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DEPARTMENT OF COMMERCE • UNITED STATES OF AMERICA

# INSTITUTE FOR TELECOMMUNICATION SCIENCES
# OF THE
# NATIONAL TELECOMMUNICATIONS AND
# INFORMATION ADMINISTRATION

## ANNUAL TECHNICAL PROGRESS REPORT 1981

For the period from Oct. 1, 1980 through Sept. 30, 1981

I

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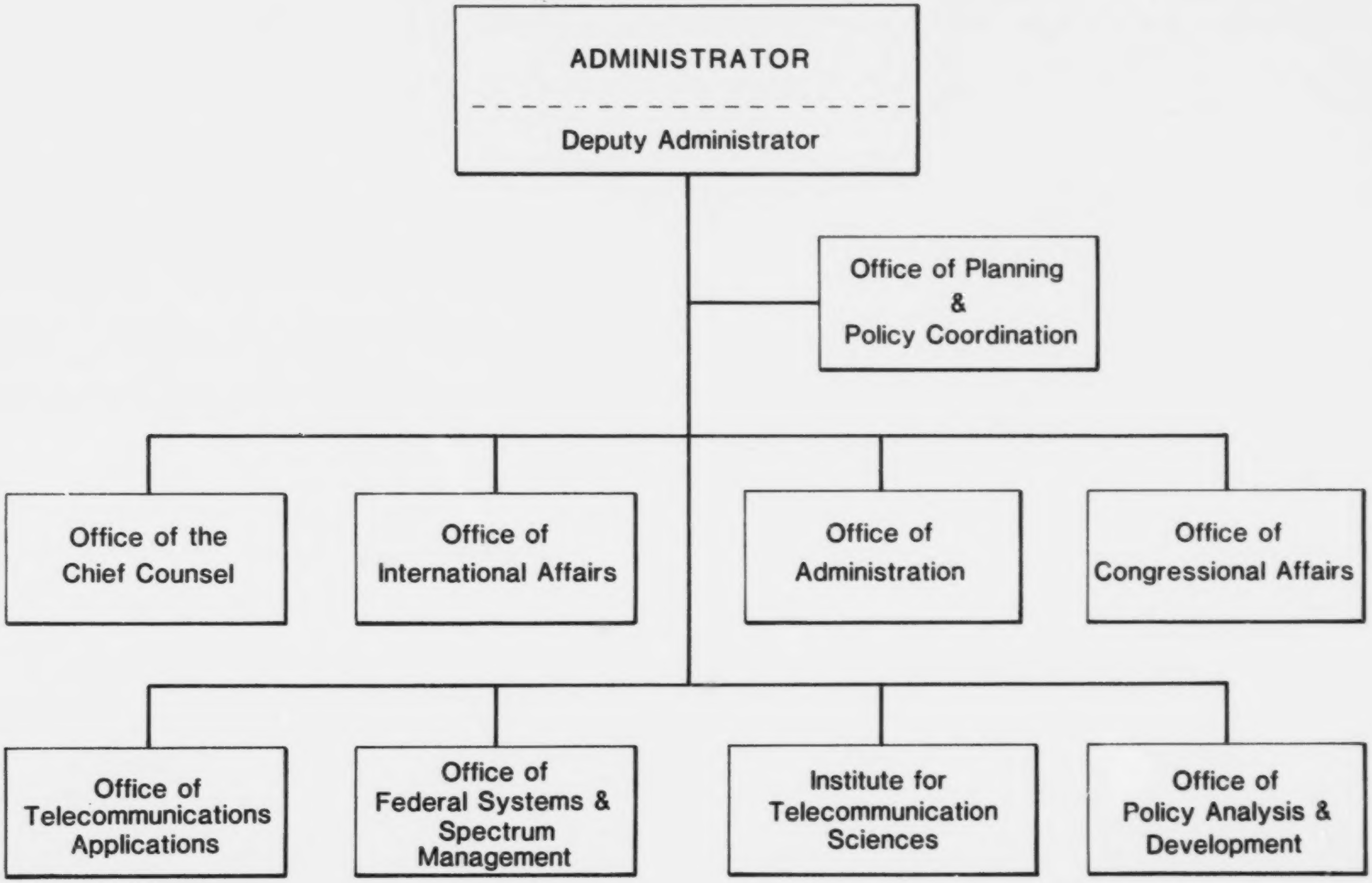
## U.S. DEPARTMENT OF COMMERCE

## National Telecommunications and Information Administration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# ITS

# ANNUAL TECHNICAL PROGRESS REPORT 1981

For the period

October 1, 1980 through Sept. 30, 1981

**U.S. DEPARTMENT OF COMMERCE**
**Malcolm Baldrige, Secretary**
Bernard J. Wunder, Jr., Assistant Secretary
for Communications and Information

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# INTRODUCTION

This annual report reviews the activities and accomplishments of the Institute for Telecommunication Sciences for the fiscal year ending September 30, 1981. It is intended to serve as a reporting mechanism to the agency management, to our other agency sponsors, and to interested members of the public.

The Institute for Telecommunication Sciences (ITS) is the chief research and engineering arm of the National Telecommunications and Information Administration (NTIA), U.S. Department of Commerce. Its mission may be divided into two major elements: 1) to provide direct support to the NTIA Administrator and the Secretary of Commerce and 2) to serve as a central Federal resource to assist other agencies of the Government in the planning, design, maintenance, and improvement of their telecommunications activities. The work performed in carrying out the latter responsibility is reimbursable, is relevant to national goals and commitments, cannot be readily performed by the private sector, and contributes to NTIA's goals.

In order to meet the responsibilities assigned to it by NTIA and the Department of Commerce and to meet requests placed upon it by other Federal agencies, the program carried out by the Institute falls under two broad categories: Spectrum Research and Analysis and Systems and Networks Research and Analysis.

The program of Spectrum Research and Analysis includes research directed toward development of models of radio-wave transmission applicable to optimization of spectrum use and communication system performance prediction. It also includes research directed toward developing spectrum use concepts and models which can lead to more efficient use of the spectrum resource; this is primarily related to the interactions between radio systems and the electromagnetic environment.

Since radio waves are strongly influenced by the environment in which they propagate, the transmission models, depending upon radio frequency, account for the effects of terrain electrical properties, shape, and surface cover; the non-ionized lower atmospheric gases, meterology, and spatial structure; and the highly variable time and spatial properties of the ionized region of the upper atmosphere. These models then provide statistical estimates of signal attenuation, dispersion, multipath, and other factors which determine the rate of information transmission and quality of performance systems provide. With additional information obtained from measurement and evaluation of the spectrum-consuming properties of antennas, receivers, and transmitters and from measurement of spectrum occupancy, development of spectrum planning techniques and ways of more intensively sharing the spectrum have resulted from work in this program. These efforts relate to NTIA and FCC roles in spectrum management.

The Systems and Networks Research and Analysis program conducts studies directed toward assessing and developing domestic and international technical performance standards to facilitate competition in the provision of enhanced telecommunication products and services and to expand U.S. industry opportunities to compete in international markets. Also, technology alternatives for the development of competitive, lower cost, communication networks are investigated; and research and analysis of advanced networks for future application are done.

In both program categories, significant involvement in the activities of the International Telecommunication Union (ITU) and, especially, its major subdivisions, the International Consultative Committees on Radio (CCIR) and Telephone and Telegraph (CCITT), has been essential and continues a long history of active involvement by Institute staff in such activities. Work in support of these international commitments is reported within the succeeding chapters at relevant places.

In total, the work summarized in this report is intended to assist in maximizing the efficient use of the national spectrum resource, the efficient use of Government telecommunication systems, and new technology toward achieving national goals. It is directed toward incorporating technical, economic, market, regulatory, and other factors in an integrated manner into policy development and toward translating Administration policy for use in national and international arenas.

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# CHAPTER 1. EFFICIENT USE OF THE SPECTRUM

The radio, or electromagnetic, spectrum has seen dramatic growth in demand and use since the beginning of World War II. A great range of new spectrum-dependent services has evolved. American industry, government, and private citizens have put the spectrum to work in such profusion that now saturation appears imminent and, in some cases, has already occurred. To provide for new and expanded use, two major alternatives exist. One is to exploit new regions of the spectrum at progressively higher frequencies. The second is to provide physical principles upon which spectrum use depends and, complementing this understanding, provide for more effective means of managing spectrum use.

Spectrum use by the U.S. Government alone is growing nine percent annually in those frequency regions where equipment is readily available. Embryonic efforts are being made to use the even higher frequencies above 10 GHz for many applications where equipment still remains to be developed.

The National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS), conducts a program of research and development which addresses both of these alternatives. Much of the work being done to extend the use of the spectrum to higher frequencies is discussed in Chapter 3 of this report, Electromagnetic Wave Transmission. That chapter also provides brief mention of some of the work being done to improve our understanding of propagation problems in those regions of the radio spectrum that are already extensively used.

In this chapter, some highlights of the NTIA/ITS program directly concerned with spectrum engineering are reviewed. Many of these spectrum engineering projects draw heavily on experience from other programs in ITS, including antenna design and measurement, channel characterization and system performance, and the many propagation related efforts.

## SECTION 1.1. SPECTRUM ENGINEERING TECHNIQUES

We are concerned here with those techniques which can be used by policy makers, frequency managers, system designers and planners, and others concerned with the use of spectrum dependent systems in the increasingly congested real world. These are techniques that define the extent to which realistic sharing of frequencies, time, and space is possible. They also address problems in optimum choice of frequencies and rational trade-offs between limits on broad classes of equipment (limits on factors such as antenna height or power), the ability of a system to provide a required service, and the efficiency with which available spectrum is used. Techniques of this kind are extremely varied and must address a wide range of problems from the very specific (for the designer of a specific system at a particular location) to the very general (for the policy maker and regulator who must consider national or regional consequences in a single action).

Traditionally, spectrum engineering techniques have been developed to evaluate a specific situation, usually with a series of "safe" or "conservative" assumptions. Conservatism allowed for some simplicity in these techniques, but even so, they were arcane enough so that relatively few people used them, and even fewer understood them.

Our goals in this part of the program are to develop a family of such techniques that is based on a sound knowledge of the physical characteristics of the problem, the technical properties of equipment involved, the practical way in which that equipment is used, and the influence of the natural environment. If we are successful in developing such techniques, they are necessarily complex and, in their initial form, difficult to use and understand. We are aggressively working to overcome these barriers to effective use by careful documentation and by developing computer methods that are easily used and provide results in the user's context.

Conservatism in many cases equates to wasted spectrum. We address this problem by building techniques which incorporate a comprehensive statistical analysis of the many variables (and their complex interactions) which affect the results. By so doing, we allow the users to be as liberal or conservative as they choose.

For over a decade, government, academic, and industrial groups have advocated development of methods for improving the overall effectiveness of spectrum use (as opposed to the optimization of individual system performance). This concern paralleled and even predated similar realizations that ideal common use of environmental resources such as air and water may not coincide with economic maximization of an individual user's profits.

The developments reported here are discussed with current applications in mind. But their true value lies in their general character. In most cases, these methods can be adapted to meet many new requirements involving a broad range of telecommunications needs and services. The presentation of summary results in graphic form (particularly as maps and map overlays), the development of demographic results, and the design of interactive computer programs that make it easy to ask "*what if?*" questions are indicative of our continuing effort to bridge the gap between technology and the planners and policy makers.

The *Broadcast Frequency Assignment Strategies* project has developed computerized methods for assigning frequencies to transmitters so that all applicants can be satisfied in the smallest-possible bandwidth.

Frequency-distance (F*D) separation rules are a part of the frequency management process in many services. In a channelized service, these take the form: cochannel transmitters must be separated by at least $d_0$ km, adjacent channel transmitters must be separated by at least $d_1$ km, transmitters separated by two channels must be at least $d_2$ km apart, etc.

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VHF and UHF television broadcasting and FM radio broadcasting are governed by such rules. Despite the common use of such rules, no one has known how to assign individual frequencies to arbitrarily-located transmitters so as to get the maximum number of users in a specified bandwidth, nor how much additional spectrum is required to satisfy each additional F*D separation rule for a fixed number of transmitters.

The problem can be stated as follows: given a set of F*D rules for a channelized band, and a set of desired transmitter locations (arbitrary), assign channels to the transmitters so that the F*D rules are satisfied while minimizing the total bandwidth required.

A computer algorithm that solves this problem efficiently can be used in several ways. First, it can be used as an allocation tool. For example, given a characterization of a proposed service, it can accurately determine the amount of spectrum required (the allocation) together with an assignment of specific frequencies to specific locations (a table of allotments). Second, it can serve as a very fast automated tool for routine frequency assignments. Third, it can be used as a research tool for discovering general principles of spectrum management.

As an example of this last application, consider the problem of establishing an adjacent-channel frequency-distance rule in a new channelized service. The required separation will depend on the kind and quality of service desired, the propagation characteristics in the frequency band, and on emission and equipment characteristics. In particular, it depends on the transmitter emission spectrum and the adjacent-channel rejection capability of the receivers. Within rather broad limits, these equipment characteristics can be controlled by the designer. If greater adjacent-channel rejections are required, then adjacent-channel distance separations can be smaller, but the receivers will cost more. A spectrum manager would like to trade-off the equipment costs and the spectrum costs when establishing the separation rules. A general curve for the spectrum costs of an adjacent channel separation rule was determined using the computer algorithms developed in the project, and the procedure described in the next paragraph.

The cochannel separation distance, $d_0$, was taken as the unit of distance. A given density of random transmitter locations was generated. The adjacent channel separation distance was set, and there were no other F*D rules. Then the computer program produced a table of assignments minimizing the total bandwidth required. Another set of transmitter locations was generated and a table of assignments for these locations were found. Ten test problems with the same specifications except for the locations of the transmitters were solved, and the average minimum bandwidth required for these ten samples was recorded. Then the distance $d_1$ was changed, and the process was repeated for the same number of transmitters. The adjacent-channel separation distance was varied from 0 to $d_0$ for four different densities of transmitters.

The percentage increase in total number of channels needed to satisfy all applicants is shown in Figure 1-1 as a function of $R = d_0/d_1$. The shaded area in Figure 1-1 covers all the computed points.

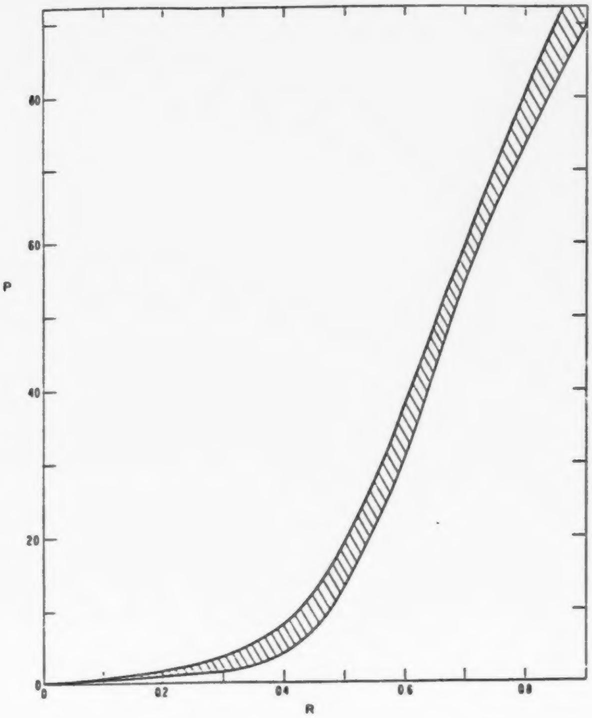


Figure 1-1. Percentage increase in required number of channels (P) as a function of adjacent-channel separation distance to cochannel separation distance (R).

If $d_1$ is small compared to $d_0$, only a few more channels are required than if there were no adjacent-channel distance separation required. As long as $d_1/d_0$ is less than about 0.4, the number of channels required increases slowly with $d_1$. In this region, a spectrum manager would probably allow receiver costs to determine the separation distance. But in the neighborhood of $d_1/d_0=0.45$, a threshold is reached, and for larger separations, small increases in the adjacent-channel separation distance, $d_1$, greatly increase the total bandwidth required to provide the service.

The methodology can be applied to analyze more complicated realistic problems, as it was in "Spectrum Efficiency as a Function of Frequency-distance Rules: An Application to UHF-TV," by W. K. Hale (to be published as an IEEE Proceedings Letter Report). The UHF "taboos" are the most complicated set of F*D rules, as shown in Table 1-1. In recent years, the Federal Communications Commission has sponsored research aimed at reducing or eliminating some of these taboos. Hale analyzed the effect of changing the taboos on the total bandwidth required to provide various levels of service. For example, if all the non-cochannel taboos were eliminated, the same number of stations could be assigned in 70% of the bandwidth required by the taboos. This can be analyzed by comparing Table 1-1 with Figure 1-1. Only one separation distance is greater than 0.45 of the cochannel separation distance -- the one for a separation of 15 channels. Figure 1-1 shows that this tabooo alone would increase the spectrum required by about 15%. The taboos for channel separations 14, 7, and 1 contribute most of the rest of the required increase.

On the other hand, increasing the separation distances on these 4 channels would consume much more spectrum because then the distances would be above the knee of the curve in Figure 1-1. For example, if all the taboo separation distances were doubled, it would take 2.4 times as much spectrum to provide the service.

Table 1-1. UHF-TV Taboos

| Channel Separation | Required Distance Separation |
|---|---|
| 0 (cochannel) | 155 miles |
| 1 | 55 miles |
| 2 | 20 miles |
| 3 | 20 miles |
| 4 | 20 miles |
| 5 | 20 miles |
| 7 | 60 miles |
| 8 | 20 miles |
| 14 | 60 miles |
| 15 | 75 miles |

The computer algorithm which solves the frequency assignment problem is described in a technical report, "New Spectrum Management Tools: Automated Frequency Allocation and Assignment Algorithms," by W.K. Hale and D.H. Cronin (to be published as an NTIA report).

In 1980, the International Radio Consultative Committee (CCIR) of the International Telecommunications Union (ITU) adopted Recommendation 506, which defines interference, and suggests that the definition will be used in the International Radio Regulations for deriving sharing criteria. Because of the variabilities of equipment characteristics, transmission loss, and (for some services) location and traffic intensity, only probabilistic estimates of interference are realistic. A formula for calculating the probability of interference developed in the Tradeoffs for Efficient Use of the Spectrum project has been presented to CCIR Study Group 1, and probably will be approved at the final meetings in October of 1981.

Recommentation 506 defines interference as "the effect of unwanted energy...upon reception in a radio communication system, manifested by any performance degradation, misrepresentation, or loss of information which could be extracted in the absence of such unwanted energy." Let

A denote "The desired transmitter is transmitting."

B denote "The wanted signal is satisfactorily received in the absence of unwanted energy."

C denote "Another equipment is producing unwanted energy."

D denote "The wanted signal is satisfactorily received in the presence of the unwanted energy."

All of these statements refer to the same small time period. Then according to Recommendation 506, interference means "A and B and C and D*," where D* is the negation or opposite of D. Let P(x) denote the "probability of x," and P(x|y) denote the "probability of x, given y." Then, the probability of interference during the small time period is

$$P(I) = P(A \text{ and } B \text{ and } C \text{ and } D^*) \quad (1)$$

which can be expressed in terms of known or computable quanities:

$$P(I) = [P(B|A) - P(D|A \text{ and } C)]\, P(A \text{ and } C) \quad (2)$$

It may be preferable to consider the probability of interference during only the time that the wanted transmitter is transmitting. This probability is

$$P'(I) = P(B \text{ and } C \text{ and } D^*|A) \quad (3)$$

which can be reduced to

$$P'(I) = [P(B|A) - P(D|A \text{ and } C)]\, P(C|A) \quad (4)$$

First, consider the difference between (2) and (4). The probability of interference can be interpreted as the fraction of time that interference exists. In Equation (2), this fraction is the number of seconds of interference during a time period divided by the number of seconds in the time period. In Equation (4), the fraction is the number of seconds of interference divided by the number of seconds the wanted transmitter is transmitting during the time period. This second fraction is larger than the first unless the wanted transmitter is on all the time.

P(B|A) is just the probability that a wanted signal will be correctly received when there is no interference, often expressed as the probability that $S/N \geq R$, where S is the signal power, N is the noise power, and R is the signal-to-noise ratio required for satisfactory service. In some services, this probability is called the reliability, and is often computed when the system is designed. It can be computed if system parameters (for example, transmitter and receiver location, power, required S/N) are known using statistical data on radio noise.

Many systems, such as satellite or microwave relay point-to-point systems, are designed so that $P(B|A) \approx 1$. In other services, such as long-distance, ionospheric, point-to-point services, or mobile services near the edge of the coverage area, P(B|A) may be quite small. In this latter case, the probability of interference will be small regardless of the other probabilities.

P(D|A and C) is the probability that the wanted signal will be correctly received even when the unwanted energy is present. It can be computed if there is sufficient information about the location, frequency, power, etc., of the source of unwanted energy.

P(A and C) is the probability that the wanted transmitter and the source of unwanted energy are on simultaneously. In some situations, the wanted transmitter and source of unwanted energy may be operated independently. For example, they may be on adjacent channels, or beyond a coordination distance. In this case, P(A and C) = P(A)P(C), where P(A) is the fraction of time that the wanted transmitter is emitting, and P(C) is the fraction of time that the unwanted source is on.

In other situations, the operation may be highly dependent. For example, the transmitters may be cochannel stations in a disciplined mobile service. In this case, P(A and C) is very small (perhaps not zero, because a station can be located so that it causes interference even when it cannot hear the other transmitter).

The two transmitters might both operate continuously. For example, one might be part of a microwave point-to point service, and the other a satellite sharing the same frequency band. In this case, P(A and C) = 1, and the probability of interference depends entirely on the factor in square brackets in Equation (2).

Similarly, P(C|A) = P(C) if the transmitters operate independently; P(C|A) is very small if the two transmitters are cochannel stations in a disciplined land mobile service; and P(C|A) = 1 if the unwanted transmitter is on all the time.

In general, all the terms in Equations (2) and (4) affect the probability of interference, although their relative importance is different in different services.

Equations (2) and (4) give the probability that interference will occur at an instant of time. A more conservative view is that interference occurs if any part of a transmission is lost; that is, if the unwanted energy causes loss of information any time during the wanted trasnmission. This is particularly applicable to digital transmission systems. In this case, we replace the factor P(C|A) in Equation (4) with the probability that the wanted and unwanted transmissions overlap.

If both the wanted transmission and the unwanted energy are present all the time, this probability is one. The interesting case is when one or both transmit intermittently. Let

$T_w$ = the length of a transmission by the wanted transmitter;

N = the average number of unwanted emissions per unit time; and

$T_{ua}$ = the average length of an unwanted emission.

Assume that the beginning time of the unwanted emission is Poisson distributed, and the length of the quiet times is exponentially distributed. Then the probability that the wanted and unwanted transmissions overlap is:

$$P(\text{overlap}) = 1-(1-NT_{ua})\exp[-T_wN/(1-NT_{ua})]. \quad (5)$$

Substituting (5) into (2), yields the probability of interference at some time during a transmission of length $T_w$:

$$P(\text{interference}|T_w) = [P(B|A - P(D|A \text{ and } C)]$$
$$\times [1 - (1-NT_{ua})\exp[-T_wN/(1-NT_{ua})] \quad . \quad (6)$$

Notice that $NT_{ua}$ is the fraction of time that the unwanted energy is present. If $NT_{ua} = 1$, then P(overlap)= 1. If $NT_w$ and $NT_{ua}$ are both much smaller than 1 (both operations are very intermittent) then $P(\text{overlap}) \approx NT_w + NT_{ua}$.

In addition, this project subcontracted a study of the interference from several cochannel FM transmissions to FM reception. Dr. David Middleton is conducting this study. Fundamental formulas for the interference have been derived, and will be published.

The UHF Comparability project has provided methods for improving the assignment of UHF TV channels. In the past, assignments have been based upon a simplified method to minimize administrative burden. However, with many of the allocations filled, and the recent prospects of low-power drop-in stations, a much more complex method was needed that could include terrain effects on the propagation, antenna patterns, and the actual system parameters of both the existing stations and the applicant stations. In addition, each assignment has to consider the potential interference caused by intermodulation, image frequencies, etc. (commonly called taboos). In order to add a new station to a particular market, whether it be a full power station or a low-power drop-in station, requires searching the existing assignments for potential interference problems. A computer program was written to access a copy of the FCC TV data base, select the stations in the area that might have interference, and print out data in order to determine potential channels in the area. A sample of the output is shown in Figure 1-2 for Boston, MA. In order to put a station into an area as crowded as Boston, all of the station parameters will have to be engineered. That is, under the current rules just using distance separations, no new stations could be placed in Boston. However, by scanning the output of this program, it is possible to find channels where, with some power restrictions and directional antennas, it may be possible to put in some low-power stations. For instance, in the example, a Channel 50 assignment would conflict with Channels 36 and 64 (in violation of the sound image taboos by 27% and 40%). We can determine the power restrictions on a new Channel 50 that would not exceed established signal-to-interference ratios within the coverage areas of Channels 36

| Vacant Channel Number | Taboo | Call Sign | Taboo Channel Number | Distance from Reference | Azimuth from Reference | Latitude (Deg.N) | Longitude (Deg.E) |
|---|---|---|---|---|---|---|---|
| 35 | ADJACENT CHANNEL | WSBETV | 36 | 43.93 MI | 209.09 | 41.8050 | 71.4733 |
| 35 | LOCAL OSCILLATOR | | 28 | 50.50 MI | 172.35 | 41.6369 | 70.9281 |
| 35 | LOCAL OSCILLATOR | NEW | 28 | 54.38 MI | 186.97 | 41.5800 | 71.1861 |
| 35 | VIDIO IMAGE | | 50 | 48.05 MI | 334.93 | 42.9911 | 71.4614 |
| 36 | CO-CHAN | WSBETV | 36 | 43.93 MI | 209.09 | 41.8050 | 71.4733 |
| 36 | CO-CHAN | WSBETV | 36 | 43.93 MI | 209.09 | 41.8050 | 71.4733 |
| 36 | IF BEAT | WGBXTV | 44 | 9.80 MI | 248.83 | 42.3103 | 71.2372 |
| 36 | IF BEAT | WGBXTV | 44 | 9.80 MI | 248.83 | 42.3103 | 71.2372 |
| 36 | INTER MODULE | WSBKTV | 38 | 9.13 MI | 243.87 | 42.3033 | 71.2189 |
| 36 | INTER MODULE | WSBKTV | 38 | 9.13 MI | 243.87 | 42.3033 | 71.2189 |
| 36 | SOUND IMAGE | | 50 | 48.05 MI | 334.93 | 42.9911 | 71.4614 |
| 36 | VIDIO IMAGE | | 21 | 63.23 MI | 337.44 | 43.2061 | 71.5403 |
| 36 | VIDIO IMAGE | NEW | 21 | 64.95 MI | 334.97 | 43.2125 | 71.6042 |
| 37 | ADJACENT CHANNEL | WSBETV | 36 | 43.93 MI | 209.09 | 41.8050 | 71.4733 |
| 63 | VIDIO IMAGE | NEW-T | 48 | 41.63 MI | 206.69 | 41.8225 | 71.4217 |
| 64 | CO-CHAN | WNET | 64 | 36.06 MI | 199.85 | 41.8703 | 71.2964 |
| 64 | CO-CHAN | WNET | 64 | 36.06 MI | 199.85 | 41.8703 | 71.2964 |
| 64 | IF BEAT | | 56 | .00 MI | 30.59 | 42.3617 | 71.0583 |
| 64 | IF BEAT | WLVITV | 56 | 9.13 MI | 243.87 | 42.3033 | 71.2189 |
| 64 | INTER MODULE | NEW-T | 62 | 1.61 MI | 231.69 | 42.3472 | 71.0831 |
| 64 | INTER MODULE | WQTV | 68 | 1.61 MI | 231.69 | 42.3472 | 71.0831 |
| 64 | SOUND IMAGE | | 50 | 48.05 MI | 334.93 | 42.9911 | 71.4614 |
| 65 | CO-CHAN | WEDY | 65 | 118.90 MI | 233.74 | 41.3283 | 72.9070 |
| 65 | CO-CHAN | W65AM | 65 | 108.93 MI | 325.43 | 43.6539 | 72.2953 |
| 65 | INTER MODULE | NEW-T | 62 | 1.61 MI | 231.69 | 42.3472 | 71.0831 |
| 65 | INTER MODULE | WQTV | 68 | 1.61 MI | 231.69 | 42.3472 | 71.0831 |
| 65 | ADJACENT CHANNEL | WNET | 64 | 36.06 MI | 199.85 | 41.8703 | 71.2964 |

Figure 1-2. Sample output from TV taboo search program around reference site at 42.36167 deg. N and 72.05833 deg. E.

and 64. The next step is to use another program to calculate what signal levels one can tolerate in the directions of those two conflicts, and limit the power from the new station in those directions. Both of these conflicts are relatively close in bearing, 200° and 210° from the new station. A sample output from the signal-to-interference calculation program is shown in Figure 1-3.

The current FM broadcast rules do not allow second- and third-adjacent-channel transmitters to be any closer to existing transmitters than the distance to the existing transmitter's protected contour (i.e., 15 miles for Class A, 40 miles for Class B, and 65 miles for Class C transmitters). However, if the FCC maintains its requirement to provide an audio signal-to-interference ratio of 30 dB and its policy to develop rules based on good quality receivers, then we believe there may be good reason to reduce the second- and third-adjacent-channel minimum mileage separation requirements, based on the performance of today's median FM broadcast receiver. The Expanded FM Spectrum Capacity project provided for the review of existing measurements of FM receiver properties and the laboratory measurement of additional receivers to establish the basis for these conclusions.

A set of interference-rejection measurements made by the FCC in 1947 on eight FM broadcast receivers established the receiver specifications which defined the FM broadcast transmitter separation requirements that still are used today. The measurements were based on an audio desired-to-undesired signal ratio of 30 dB. At this ratio, the undesired signal is perceptible; at a ratio of 20 dB the undesired signal is annoying; while at a ratio of 50 dB, the undesired signal is barely perceptible. The 30 dB ratio remains as the present FCC audio-frequency protection ratio standard. As defined by the CCIR, "the audio-frequency protection ratio is the agreed minimum value of the audio-frequency signal-to-interference ratio considered necessary to achieve a subjectively defined reception quality." Corresponding to the audio protection ratio, the CCIR states "the radio-frequency protection ratio is the value of the radio-frequency wanted-to-interfering signal ratio that enables, under specified conditions, the audio-frequency protection ratio to be obtained at the output of a receiver." Obviously the rf protection ratio will be different whether the desired and interfering signals are cochannel, first-adjacent channel, second-adjacent channel, etc. The FCC has stated that the rf protection ratios should be 20 dB for cochannel, 6 dB for first-adjacent-channel, -20 dB for second-adjacent-channel, and -40 dB for third-adjacent-channel interference. Note that these rf protection ratios are established regardless of whether the desired signal and the unwanted signal are broadcasting stereo or mono transmissions.

Nationally, the IEEE has established a standard for making FM broadcast receiver measurements; internationally, the CCIR has recommended a standard that differs from the IEEE standard.

The IEEE standard method for making FM receiver protection ratio measurements utilizes tones to measure the interference between a desired signal and an interfering one. The measurement is defined only for measuring the effects of a monophonic interfering signal to a monophonic desired signal. Protection ratios for stereophonic operation are undefined. The original FCC Laboratory protection ratio measurement method is very similar to that defined by the current IEEE procedure as both use tones to set levels and measure interference.

The CCIR protection ratio measurement method utilizes noise shaped to simulate program material as the source of modulation for the interfering signal. CCIR also assumes the interfering signal to be monophonic while the desired signal is stereophonic; they contend that this presents the worst case interference situation.

The IEEE method employs standard laboratory equipment and is rather simple to perform, whereas the CCIR method requires special-purpose equipment and is somewhat critical to set-up and perform.

In Figures 1-4 and 1-5 we have combined all IEEE and CCIR method protection ratio measurement data that we have collected on contemporary receivers. These results show a significant improvement in receiver performance over the receivers available when the FCC's measurements were made. There is very little measurement data on contemporary receivers beyond second-adjacent-channel (400 kHz) carrier separations of the desired and undesired signals. However, it is interesting to compare the median rf protection ratio performance of contemporary receivers with that of the 1947-era receivers (see Table 1-2). Note that the median contemporary receiver has an rf protection ratio at second-adjacent-channel spacing (and beyond) that is as good as the median 1947 receiver had at fourth-adjacent-channel spacing (and beyond).

The Spectrum Engineering Development Support project provides analysis support to the Spectrum Engineering and Analysis Division of NTIA.

In many congested spectrum-use environments, there is significant variability in almost every factor influencing communications success. Transmitters may be mobile or their locations may be unknown, either because data are not available or because the systems have not yet been deployed. Antenna heights may depend on availability of favorable locations or on desired coverage of individual systems. Transmitter powers may vary by specification or because of aging and different maintenance procedures. Transmission loss varies with details of the transmission path and often with time because of weather or other geophysical events. Message traffic or channel usage may vary with the requirements of the users. Therefore, any realistic estimate of communications success must be probabilistic. It should be based on consideration of the statistical distribution of all significant factors.

```
                  CHANNEL    HAAT      ERP      DELTA-H
                 --------- --------- --------- ---------
                             (FT)      (KW)       (M)
    EXISTING        64        522    1480.00     51.38
    VACANT          50        500       1.00     51.38
     SEPARATION DISTANCE=  36.06

                        SIGNAL          INTERFERENCE          S/I
                    --------------    --------------     ------------
    DISTANCE         FCC   LR-AREA     FCC   LR-AREA      FCC   LR-AREA
     (S MI)         (DBU)   (DBU)     (DBU)   (DBU)       (DB)    (DB)
   -------------------------------------------------------------------
       1            132.9   132.3      39.5    61.5       93.5    70.9
       2            124.1   126.3      40.3    62.4       83.7    64.0
       3            118.2   122.8      41.2    63.3       77.0    59.5
       4            113.9   120.3      42.1    64.2       71.8    56.1
       5            110.1   118.4      43.0    65.1       67.0    53.2
       6            106.8   116.8      43.9    66.1       62.9    50.7
       7            104.0   115.4      44.8    67.0       59.2    48.4
       8            101.6   114.3      45.7    68.0       55.9    46.3
       9             99.7   113.3      46.6    69.0       53.0    44.3
      10             98.1   111.7      47.6    70.0       50.5    41.7
      11             96.7   110.0      48.5    71.0       48.2    39.0
      12             95.3   108.4      49.4    72.0       45.9    36.3
      13             94.0   106.8      50.4    73.1       43.6    33.7
      14             92.6   105.3      51.3    74.1       41.3    31.2
      15             91.3   103.8      52.3    75.0       39.0    28.8
      16             90.0   102.4      53.3    75.7       36.7    26.7
      17             88.7   101.0      54.4    76.1       34.4    24.9
      18             87.5    99.6      55.4    76.5       32.1    23.2
      19             86.3    98.3      56.5    76.9       29.7    21.4
      20             85.1    97.0      57.7    77.3       27.4    19.6
      21             83.9    95.7      58.9    77.8       25.1    17.9
      22             82.8    94.4      60.1    78.3       22.7    16.1
      23             81.6    93.1      61.3    78.9       20.3    14.2
      24             80.4    91.9      62.6    79.5       17.8    12.4
      25             79.3    90.7      63.9    80.2       15.4    10.5
      26             78.1    89.5      65.2    81.0       12.9     8.5
      27             77.0    88.3      66.5    81.8       10.5     6.4
      28             75.8    87.1      67.8    82.8        8.0     4.3
      29             74.6    85.9      69.4    83.9        5.3     2.0
      30             73.5    84.8      71.1    85.2        2.4     -.4
      31             72.3    83.7      73.1    86.8        -.8    -3.1
      32             71.2    82.5      75.5    88.7       -4.3    -6.1
      33             70.0    81.4      78.4    91.1       -8.4    -9.7
      34             68.9    80.3      82.1    94.6      -13.3   -14.4
      35             67.7    79.2      87.4   100.6      -19.7   -21.5
      36             66.6    78.1      96.4   160.6      -29.9   -82.6
```

Figure 1-3. A sample output from the signal-to-interference calculation program. HAAT is the height above average computed terrain irregularly.

| OFFSET FROM CARRIER (KHZ) | MAX (DB) | MIN (DB) | MEAN (DB) | STD DEV (DB) | RF PROTECTION RATIO (DB) EXCEEDED BY THE GIVEN PERCENT OF THE MEASUREMENTS 10% | 50% | 90% |
|---|---|---|---|---|---|---|---|
| -400. | -81.0 | -12.0 | -51.7 | 18.2 | -71.0 | -51.7 | -25.4 |
| -300. | -68.3 | 3.5 | -34.1 | 21.0 | -65.7 | -29.0 | -2.0 |
| -200. | -28.5 | 21.5 | -4.5 | 8.8 | -13.0 | -5.9 | 6.7 |
| -150. | -8.9 | 23.2 | -.4 | 7.2 | -8.0 | -1.5 | 8.6 |
| -100. | -7.0 | 22.7 | 1.6 | 6.7 | -6.1 | .8 | 11.4 |
| 0. | -18.8 | 24.7 | 3.6 | 7.2 | 0.0 | 1.4 | 20.0 |
| 100. | -18.8 | 22.5 | 1.6 | 6.7 | -2.1 | .5 | 8.8 |
| 150. | -10.9 | 23.7 | .3 | 6.8 | -6.9 | -.5 | 6.8 |
| 200. | -28.0 | 22.7 | -4.4 | 9.2 | -14.8 | -5.2 | 4.4 |
| 300. | -66.0 | -1.0 | -26.9 | 17.5 | -52.3 | -23.1 | -5.4 |
| 400. | -81.0 | -13.9 | -49.1 | 17.3 | -67.0 | -52.6 | -24.1 |

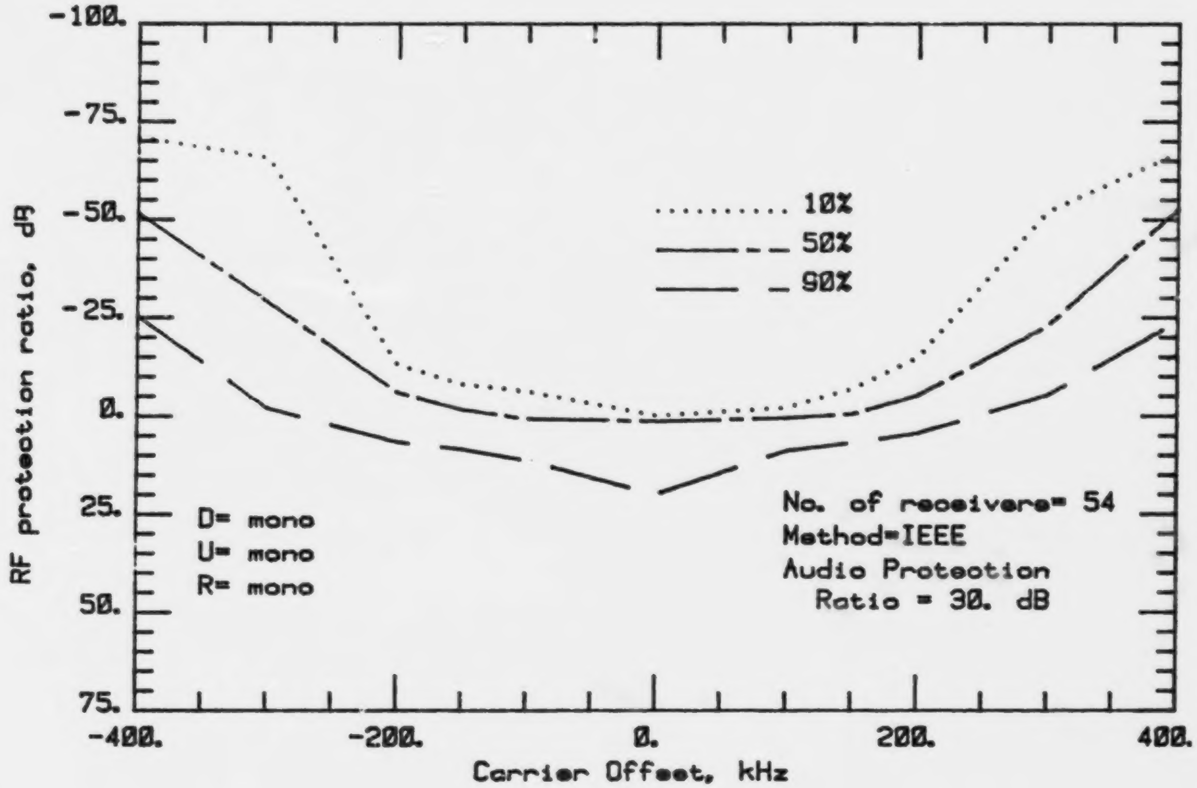


Figure 1-4. All available IEEE method rf protection ratio measurement data, taken on FM broadcast receivers, for monophonic desired (D) and undesired (U) signals and receiver (R) set for monophonic operation. The table provides the statistics for the protection ratio measurement data. The graph shows the measured protection ratio for at least 10, 50, and 90 percent of the FM broadcast receivers versus carrier offset between the desired and undesired FM broadcast signals.

| OFFSET FROM CARRIER | MAX | MIN | MEAN | STD DEV | RF PROTECTION RATIO (DB) EXCEEDED BY THE GIVEN PERCENT OF THE MEASUREMENTS | | |
|---|---|---|---|---|---|---|---|
| (KHZ) | (DB) | (DB) | (DB) | (DB) | 10% | 50% | 90% |
| -400. | -77.0 | 0.0 | -49.8 | 21.2 | -72.9 | -52.0 | -18.0 |
| -300. | -58.0 | -8.0 | -29.6 | 14.0 | -49.7 | -26.0 | -10.3 |
| -200. | -25.0 | 7.0 | -8.1 | 7.7 | -18.8 | -7.5 | 1.0 |
| -150. | -13.0 | 8.0 | -1.8 | 4.9 | -7.0 | -1.0 | 4.9 |
| -100. | -3.0 | 9.0 | 1.4 | 2.9 | -2.0 | 1.0 | 6.8 |
| 0. | 5.0 | 33.0 | 15.2 | 6.5 | 6.3 | 15.0 | 26.0 |
| 100. | -3.0 | 9.0 | 1.4 | 2.9 | -2.0 | 1.0 | 6.8 |
| 150. | -13.0 | 8.0 | -1.8 | 4.9 | -7.0 | -1.0 | 4.9 |
| 200. | -25.0 | 7.0 | -8.1 | 7.7 | -18.8 | -7.5 | 1.0 |
| 300. | -58.0 | -8.0 | -29.6 | 14.0 | -49.7 | -26.0 | -10.3 |
| 400. | -77.0 | -16.0 | -51.4 | 19.2 | -72.9 | -52.0 | -18.4 |

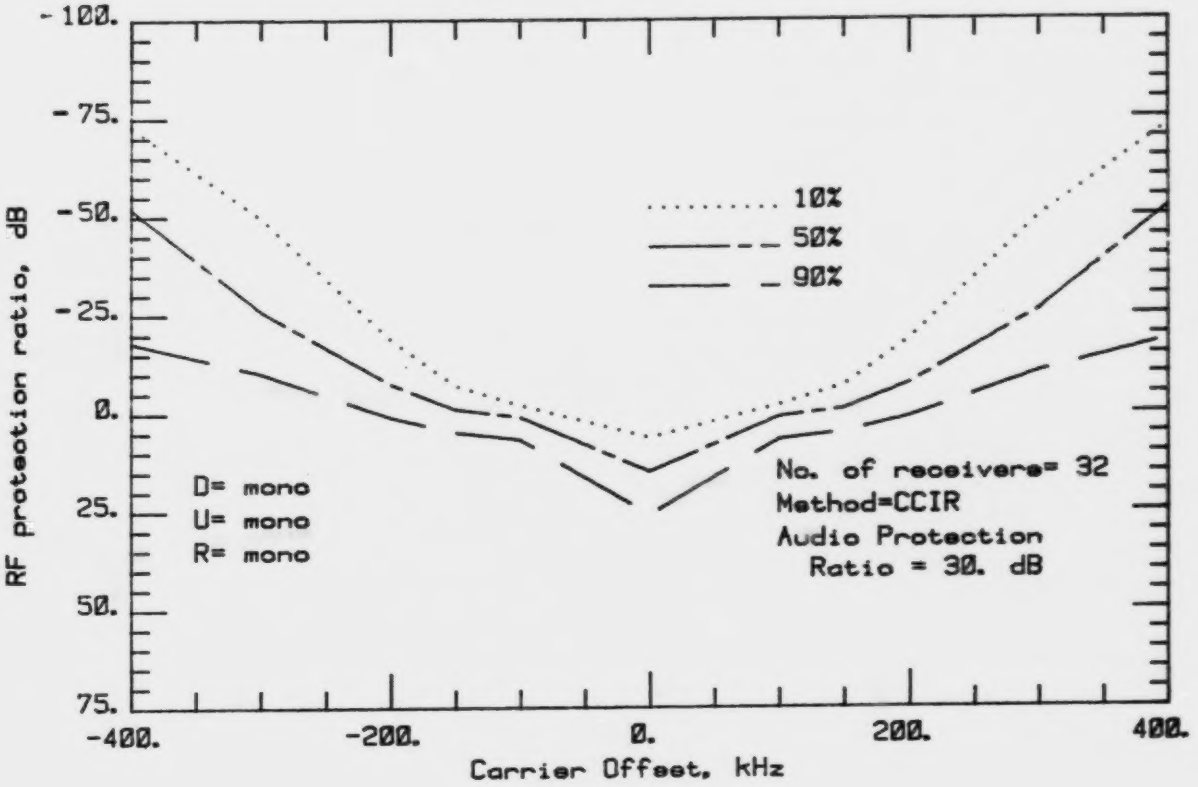


Figure 1-5. All available CCIR method rf protection ratio measurement data for monophonic desired (D) and undesired (U) signals and receiver (R) set for monophonic operation, CCIR method, 30 dB protection ratio. The table provides the statistics for the protection ratio measurement data. The graph shows the measured protection ratio for at least 10, 50, and 90 percent of the FM broadcast receivers versus carrier offset between the desired and undesired FM broadcast signals.

A computer program previously developed at ITS for computing the probability of communications was restructured this year, and installed on the FSSM computer at Annapolis. Figure 1-6 shows a functional block diagram of the program. The overall plan in the program is to compute the probability density function (pdf) of the wanted signal, then compute the pdfs of each "kind" of interference. The powers from the different sources of interfence are added together with the ambient noise to get the pdf of total noise plus interference. This sum is combined with the signal pdf to obtain the probability distribution of the signal-to-noise ratio. The probability of communications (achieving a specified signal-to-noise ratio) is then computed.

The input for the computer program is

(1) for the wanted signal,

- (a) the pdf of radiated power of the wanted transmitters,
- (b) the conditional pdf of transmission loss, given wanted path length,
- (c) the pdf of wanted path length;

(2) for each category of interferer,

- (a) the pdf of radiated power,
- (b) the conditional pdf of transmission loss, given interfering path length,
- (c) the pdf of path lengths,
- (d) the traffic intensity, U, of interferers in this category,
- (e) the receiver transfer function, if any;

(3) the pdf of ambient noise; and

(4) the required signal-to-noise ratio.

Any pdf may be given analytically, in which case the defining parameters (e.g., mean, variance) must be given, or the pdf may be defined by an input table of measured values.

The restructured program is interactive, querying the user to prompt the required input, and displaying the output immediately. The program, named PRODSIR (Probability Distribution of Signal-to-Interference Ratio), has been installed on the HP-1000 at Annapolis and Boulder, and on NOAA's large central computer at Boulder. A User's Guide will be printed soon.

In addition, a paper, "Understanding Middleton's Canonical Formula for Class A Noise," has been written and accepted for publication by the IEEE Transactions on Electromagnetic Compatibility. The paper develops an intuitive understanding of the meaning and implications of Middleton's canonical formula for Class A noise. Transformation of the formula to dBw separates the gaussian and nongausian noise components and shows the physical meaning of the model parameters. A simple scenario that produces Class A noise is described and used to interpret the canonical formula. It is shown that the canonical formula for Class A noise is valid for only a limited set of physical situations.

A knowledge of service and interference ranges associated with existing and future air navigation aids is an important part of the FAA's spectrum planning effort. Coverage, interference, and propagation prediction capabilities developed by NTIA as part of the Air Navigation Aids project are utilized to provide much of this information.

In recent years much of this effort has involved the VHF-UHF range and has included the development of computer programs, extensive sets of calculations, and the publication by the FAA of several design handbooks. One of the computer programs has also been made available to the general public, and several government and nongovernment agencies are now in the process of installing it on their own machines.

One particular effort this past year was devoted to providing the international community with a revised set of curves for air/ground and air/air propagation to be included in a proposed revision of CCIR Recommendation 528. The important change is the inclusion of curves generated by the IF-77 model for the time availabilities of .05, .50, and .95, the use of which will provide more reliable service. A sample of these revised curves is shown in Figure 1-7.

The FAA is currently interested in treating the LF-MF range in the same way as was done with the VHF-UHF range in order to produce new handbooks for the nondirectional beacons. We have therefore obtained the ground wave (and exponential atmosphere) program from the CCIR and have converted it to our system. We are now preparing to use it to make extensive high altitude calculations.

Table 1-2. Comparison of Median rf Protection Ratios for 1947-Era and Contemporary FM Broadcast Receivers

| | Median RF Protection Ratio (dB) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Desired/Undesired Channel Separation | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
| Receivers | | | | | | | | | | | |
| 1947 | -55 | -52 | -46 | -24 | 2 | 10 | -11 | -40 | -46 | -48 | -49 |
| Contemporary | — | — | — | -51 | -6 | 1 | -5 | -52 | — | — | — |

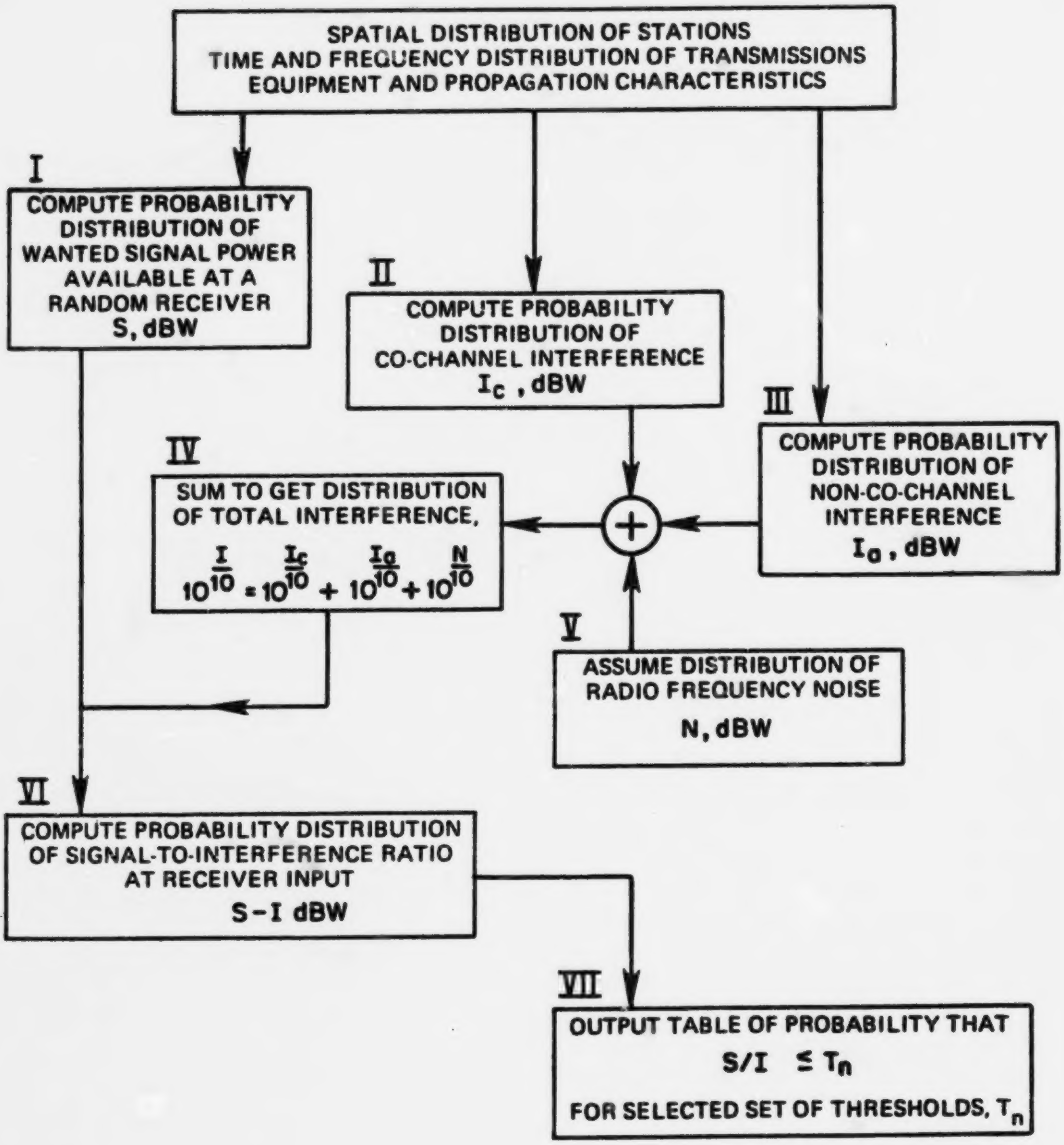
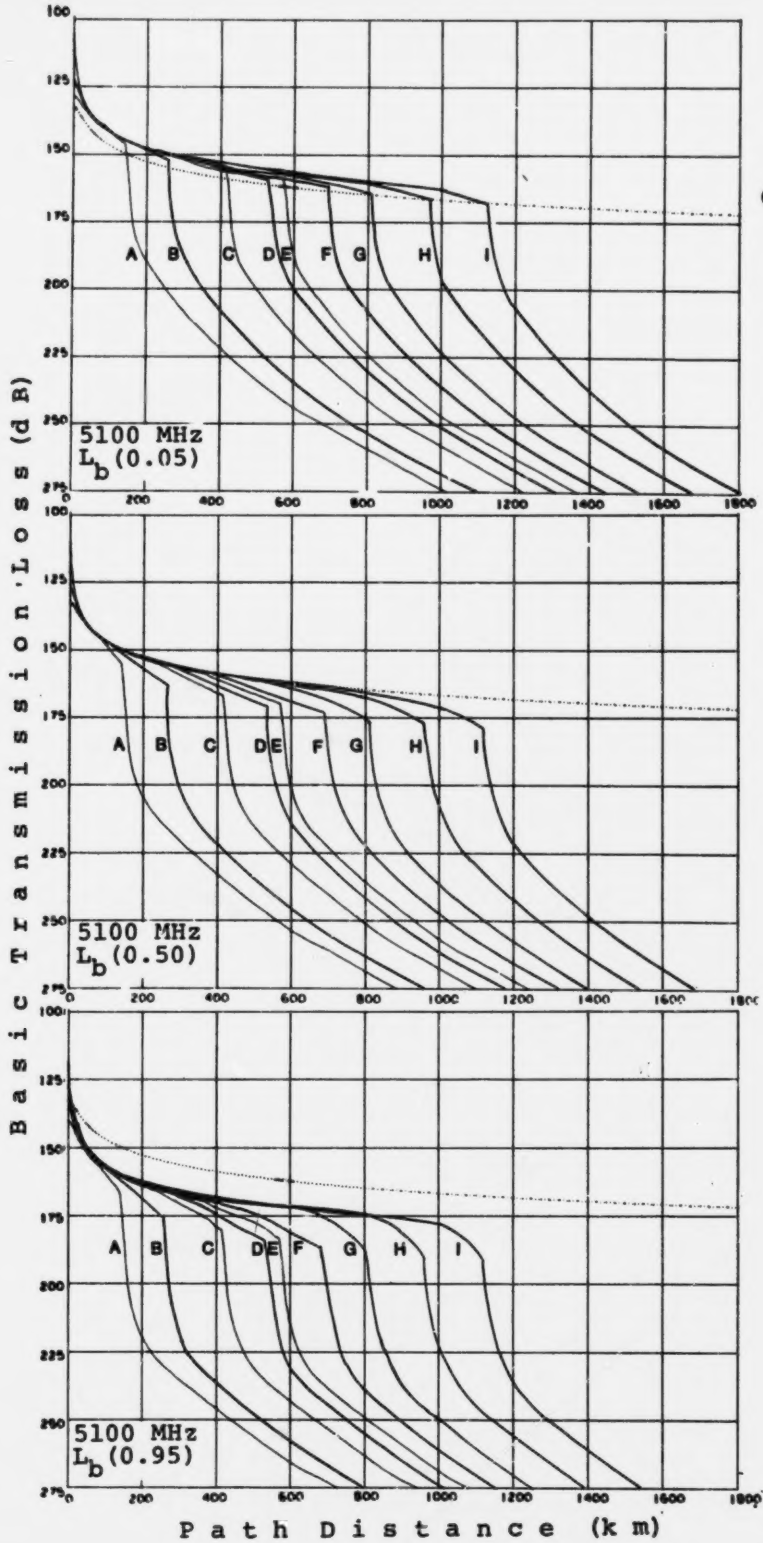

SPATIAL DISTRIBUTION OF STATIONS
TIME AND FREQUENCY DISTRIBUTION OF TRANSMISSIONS
EQUIPMENT AND PROPAGATION CHARACTERISTICS
I
COMPUTE PROBABILITY DISTRIBUTION OF WANTED SIGNAL POWER AVAILABLE AT A RANDOM RECEIVER
S, dBW
II
COMPUTE PROBABILITY DISTRIBUTION OF CO-CHANNEL INTERFERENCE
$I_c$, dBW
III
COMPUTE PROBABILITY DISTRIBUTION OF NON-CO-CHANNEL INTERFERENCE
$I_a$, dBW
IV
SUM TO GET DISTRIBUTION OF TOTAL INTERFERENCE,
$10^{\frac{I}{10}} = 10^{\frac{I_c}{10}} + 10^{\frac{I_a}{10}} + 10^{\frac{N}{10}}$
+
V
ASSUME DISTRIBUTION OF RADIO FREQUENCY NOISE
N, dBW
VI
COMPUTE PROBABILITY DISTRIBUTION OF SIGNAL-TO-INTERFERENCE RATIO AT RECEIVER INPUT
S−I dBW
VII
OUTPUT TABLE OF PROBABILITY THAT
$S/I \leq T_n$
FOR SELECTED SET OF THRESHOLDS, $T_n$

Figure 1-6. Block diagram of program for computing the probability of interference in a congested environment.



**Code for Antenna Heights**

| Code | $H_1$ (m) | $H_2$ (m) |
|---|---|---|
| A | 15 | 1000 |
| B | 1000 | 1000 |
| C | 15 | 10000 |
| D | 1000 | 10000 |
| E | 15 | 20000 |
| F | 1000 | 20000 |
| G | 10000 | 10000 |
| H | 10000 | 20000 |
| I | 20000 | 20000 |

Figure 1-7. Basic transmission loss at 5100 MHz for time availabilities of 0.5, 0.50, and 0.95. The dotted-line curve is that for free-space.

Two further tasks are currently under way:

1. Production of computer generated propagation and interference predictions as requested by the FAA. Part of this work involves the study of special cases that have presented particular problems.

2. Ongoing comparisons of predictions with experimental data and with other models.

A project has been started this year to develop a Ground Network Communication Model. This is a model of a large network of up to 300 ground-based transceivers in an area up to 50 km on a side. The model will calculate and display the communication reliablility of each link, and allow the user to modifiy the network to analyze siting, equipment characteristics, and other parameters affecting the link communication reliability. The program will use the point-to-point path-loss model to calculate reliablility for each link of the net. There are several data bases associated with the model to store such items as terrain data, map data, plot data, etc.

The Figure 1-8 shows a planned structure diagram of the model.

## SECTION 1.2. SPECTRUM ENGINEERING FOR EFFICIENT SPECTRUM USE

In addition to the development of new analytical and measurement techniques, ITS applies the results of such work to specific problems of concern to various agencies. One important factor in planning for new developments is our experience with such projects where the practical needs of operational agencies must be recognized.

The U.S. Coast Guard Consulting project provides "quick reaction" propagation predictions and short-term studies as needed by the Coast Guard in the operation of their large network of MF and VHF communication systems. In addition, seasonal propagation predictions are supplied to support the AMVER (Automated Mutual-assistance VEssel Rescue) system. These periodic predictions are distributed to the many AMVER participants to aid them in choosing the best frequency and Coast Guard communication station with which to log their AMVER reports.

One of the studies completed this year was to determine how well the U.S.-based AMVER stations could cover the Indian Ocean. The analysis here involved the prediction of the communication (or circuit) reliability between eight U.S.-based stations and an array of 49 simulated ship positions for a variety of conditions that account for diurnal, seasonal, and solar activity effects. The results of the study indicate that it is difficult, but certainly not impossible, to communicate with the ships in the Indian Ocean. The communication stations at Portsmouth and San Francisco are good choices. The best frequencies to use are in the 8, 12, and 16 MHz maritime bands. Other choices include the communication stations at Guam, Honolulu, and San Juan.

Another study begun this year involves coverage problems along the Tennessee River in the Second U.S, Coast Guard District. Several of the VHF sites used for communication with vessels on the river do not perform as well as expected. In fact, there are several sections of the river that are not covered by any of the VHF sites. ITS provides assistance in the form of propagation and coverage predictions for the sites as they are now, as well as for some alternatives, which include new sites and directional antennas for existing sites.

SPS EMC Assessment. This is a continuing program sponsored by the Department of Energy to study the potential RFI/EMI effects of a proposed Solar Power Station (SPS). These satellites would convert solar energy into dc voltage which would drive high power microwave sources to produce a high energy microwave beam at 2.45 GHz. The satellite in geostationary orbit would beam the energy to a given receiving antenna (rectenna) on earth where the microwave energy would be converted to electrical energy for consumer use. One satellite is capable of producing 5000 MW of electrical power on the earth.

The EMC study covers a broad spectrum of EM and electronic systems studies to determine effects of an SPS. The EMC evaluation program included assessments through analysis and measurement of the performance degradation of susceptible electronic systems, the utility effects of mitigation techniques relative to system applications. The evaluation included the development of investment and mitigation cost summaries for the affected systems. Reported here is the cost factor area; relating systems and applications to current investment, estimates regarding future expenditures for capability or service area enhancement, and functional mitigation incremental costs. These data are presented for six continental United States (CONUS) geographic areas. Also reported here is a summary of a study dealing with alternate frequency consideration for the power and pilot beams. The alternate frequency consideration was required to indicate the character of functional and environmental effects for alternate frequency ranges as one input to future engineering trade-off investigations.

Cost factors and investment summary: These cost factors and the distribution throughout CONUS provide one indicator of the economic impacts of the SPS interference to national services, identify in the mitigation element a cost directly attributable to SPS implementation, and one economic factor for future rectenna site analyses. Redeployment costs were not addressed, since these would be unique to specific areas and widely variant. Rectenna siting requiring movement of a group of microwave relays in isolated areas or the relocation of major facilities such as radio astronomy and supporting equipments are extreme examples of a redeployment effort.

Cost estimates for modification of existing categories of susceptibility equipment were developed with the cooperation of manufacturers, particularly relative to engineering and laboratory expenses related to circuit design and integration, and the laboratory susceptibility testing of signal channel rejection and shield effectiveness.

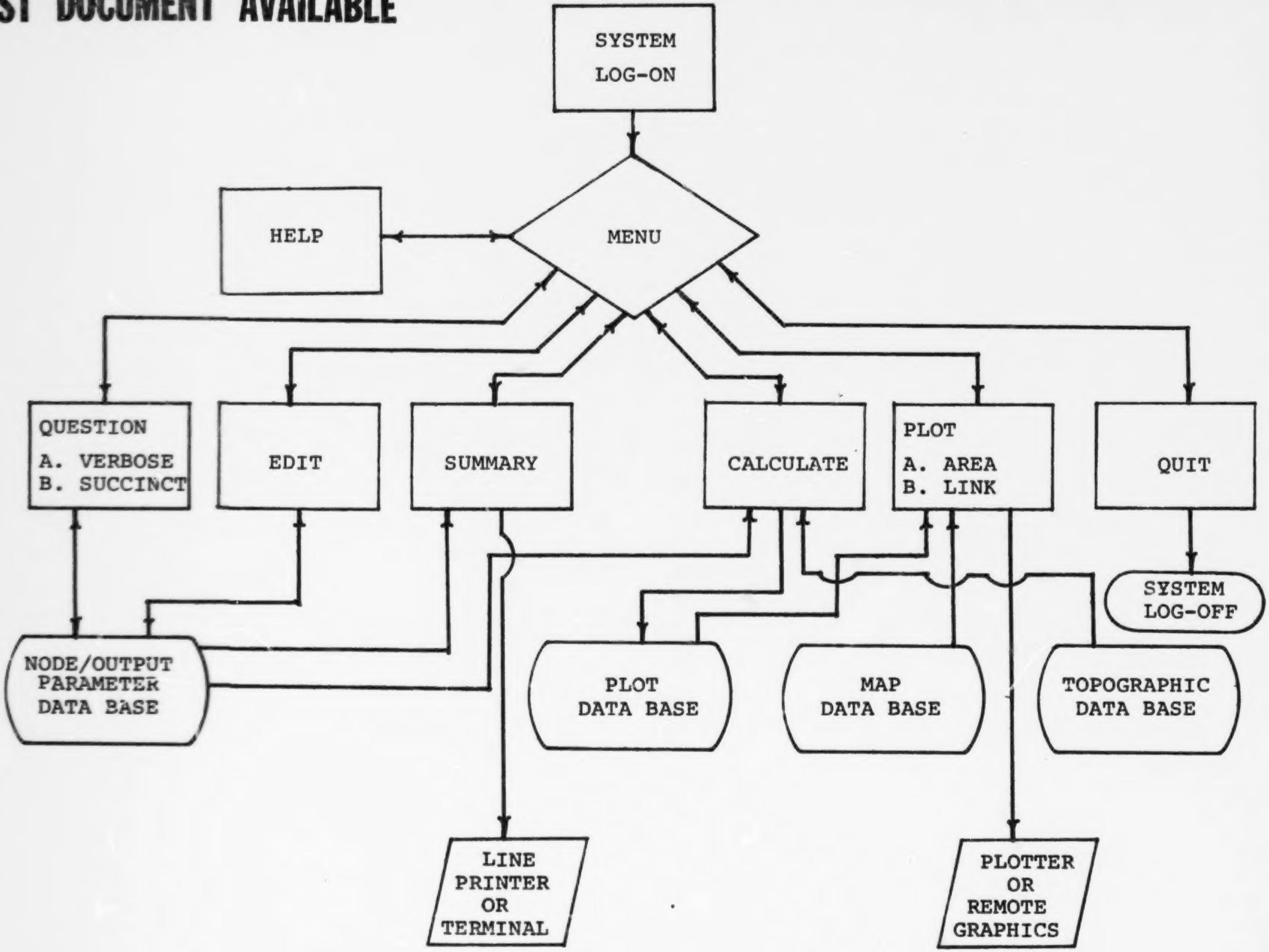

SYSTEM LOG-ON
MENU
HELP
QUESTION
A. VERBOSE
B. SUCCINCT
EDIT
SUMMARY
CALCULATE
PLOT
A. AREA
B. LINK
QUIT
SYSTEM LOG-OFF
NODE/OUTPUT PARAMETER DATA BASE
PLOT DATA BASE
MAP DATA BASE
TOPOGRAPHIC DATA BASE
LINE PRINTER OR TERMINAL
PLOTTER OR REMOTE GRAPHICS

Figure 1-8. Proposed functional structure of GNCM.

Based on the estimated number of equipments operational in CONUS that are expected to be in use for a fifteen to twenty year period, and the currently expected expansion in services requiring these systems, the possible mitigation cost range for these equipments is in the $86,000,000 to $94,000,000 range. This assumes that all equipments would be modified and tested.

Selective mitigation may be viable when specific rectenna sites are selected and spacetenna spatial and spectral emission control effectiveness has been demonstrated in laboratory and limited space tests.

Alternate frequency study: Considerations summarized herein relate to the EMC impact, SPS system elemental costs (e.g., space components, rectenna components and area, power source devices), and SPS power delivery performance and control complexities.

Frequencies lower than 2.45 GHz are not considered usable by SPS for the following reasons:

1. Increased spacetenna and rectenna areas for beamwidths comparable to the reference design.

2. Increased ionosphere interaction.

3. Increased EMC susceptibilities; larger rf receiver populations, increased SPS power beam coupling efficiencies for electronic circuitry and devices (e.g., computers and control systems, sensors).

This task was one element in the EMC evaluation of the proposed SPS Reference Design. The alternate frequency consideration was required to indicate the character of functional and environmental effects for alternate power beam frequency ranges as one input to future engineering tradeoff investigations. The basic conclusions from this task are listed as follows:

1. One positive attribute for frequencies higher than 2.45 GHz concerns the reduced ionosphere interaction, assuming the inverse frequency relationship for heating threshold. This reduced interaction would allow consideration in design and performance tradeoff exercises of spacetenna and rectenna area. As cited previously, these rectenna areas will be larger than the plots of troposphere interactions.

2. For the bands considered higher than 2.45 GHz, the increased troposphere interactions would significantly reduce the system average efficiency and increase the power beam fluctuations during storm conditions. The increased media modulation effects would greatly complicate the spacetenna control functions, including the stability of the main beam aim-point and sidelobe amplitude control loops.

3. The EMC impact on rf receivers will be reduced for the higher frequency bands because of the general use of higher gain antennas and increased processing gains and lower coupling efficiency to circuits and components. Communications and radars operating in these higher bands will employ more adaptive antenna and high processing gain techniques than systems operating at lower frequencies. These considerations are favorable for SPS higher frequency alternatives.

4. Spacetenna and rectenna areas can be significantly reduced at the higher SPS frequencies. The power beam width can be reduced by increasing the spacetenna area, generally to the $D^2/\lambda$ diameter with resulting reduction of the rectenna area, assuming a benign troposphere environment. Spatial beam modulation by refractive anomolies and rain (particularly in K band) would, however, tend to negate the advantages of a larger spacetenna.

The recommendations derived from this study are as follows:

1. Operation of the SPS in the frequency range of 5-30 GHz should not be considered because of troposphere effects on performance and system economics, and complex interference situations with future satellite and earth communicatiaons where large receiver populations are expected.

2. Operation of the SPS at lower frequencies than the 2.45 GHz Reference Design frequency should not be considered because of the greatly increased interference problems, the larger orbit station and rectenna areas required for power beam and collection efficiencies comparable to the Reference System, and the increased ionosphere interactions.

3. If for reasons not now evident, future SPS designs must seriously consider the X or K band regions, an extended scintillation and scattering measurement program would be required. Measurements in the Northeast, North Central, Northwest, Southeast, and Southwest CONUS areas over a 9-12 month period would be required to indicate meteorological variations. Data should include amplitude and phase magnitude and spectra (short and medium time windows), and spatial and temporal correlation would be required for each site to provide sufficient data for beam control function specifications and sensor citing for main beam and sidelobe measurements.

SPECTRUM RESOURCE ASSESSMENT (SRA) OF THE 5650-5925 MHz FREQUENCY BAND. This task examines the 5650-5925 MHz band to assess current and future spectrum use by both Government and non-Government services; to identify present or future compatibility problems between major users; to evaluate technically the feasibility of sharing between Government and/or non-Government services; and to recommend, where appropriate, changes to improve spectrum management procedures.

In the United States, 5650-5925 MHz has been a shared band with the primary allocation assigned to the Government radiolocation service with an industrial, scientific and medical (ISM) allocation at 5800 ± 75 MHz. There is a secondary allocation for the amateur service. To date, no use by the amateur service in this band has been documented, but an effort will continue to find present uses, if any, and any planned future use. Government allocation is for military radiolocation and is used for air-surveillance radar, transponder tracking and positive aircraft guidance, missile and rocket radio, and radar equipment. Out of the 240 assignments in this band, only 7 are non-Government and 6 of these are assigned to developers of systems which support the Government effort in this band for test and evaluation of equipment and systems.

At the 1979 World Administrative Radio Conference (WARC), the portion of this band from 5850 to 5925 MHz was reallocated to the fixed, fixed satellite (earth-to-space), and mobile services on a primary basis with radiolocation and amateur services on a secondary basis for Region 2. Interdepartment Radio Advisory Committee (IRAC) Ad Hoc 172 has recommended adding only non-Government fixed satellite services (FSS) (earth-to-space) in the 5850 to 5925 MHz band on a primary basis in the U.S. Ad Hoc 172 has also proposed U.S. Footnote YY11 which states that the FSS is limited to international systems and subject to case-by-case electromagnetic compatibility analysis. The implementation of the WARC recommendation is still in progress and implications along the northern border with Canada, and the southern border with Mexico, are not yet defined but will be a part of this assessment. The ISM band at 5800 ± 75 MHz shows little use and nothing new is planned for the near future as verified through the FCC.

To assist NTIA in fulfilling its mission, the Applied Electromagnetic Sciences Division at ITS will:

1. Review and document the characteristics of existing and proposed Government and non-Government Systems within the 5650-5925 MHz band, including those which could be expected in response to the results of the 1979 WARC and other international or national agreements.
2. Review previous compatibility analysis of systems within this band.
3. Identify and document the potential problem areas (including band edge problems with systems in adjacent bands) which may have an impact on the efficient use of the spectrum, and evaluate the feasibility of sharing between existing and proposed services.
4. Review existing technical standards and channeling plans and determine the impact of state-of-the-art technology on band usage.
5. Identify and outline specific problem areas requiring additional analysis, if any.
6. Recommend specific changes to the existing rules, regulations, and frequency management practices which would improve overall management of the band.
7. Measure frequency usage of the 5650-5925 MHz band with the Radio Spectrum Measurement System (RSMS) Van at as many locations as practical. The analysis of these measurements will be incorporated in the final SRA report.

The majority of the systems currently being used in the 5650-5925 MHz band can be classed as radars or radar activated transponders. There are a few assignments used for experimental development of new systems and antenna testing. The present assignments in the band are summerized in Table 1-3 from the Government Master File (GMF) and non-Government Master File (NGMF) according to agency and station class.

Many of the transponder transmitters operate at peak powers between 50 and 400 watts with essentially isotropic antennas. Most of the ground based radars are used for instrumentapion at the various missle test ranges. One of the most troublesome features of these radars is that of the high peak power (1 MW) and high antenna gain (~45 dB) combined with the pointing angle during a tracking exercise; there is some probability that there may be interference between these large radars and communications satellites which will operate in the upper portion of the band in the future. EMC analysis is now underway to study the possible problems within the band.

## SECTION 1.3. ADVANCED INSTRUMENTATION AND SPECTRUM MEASUREMENTS

Many forms of system design, spectrum engineering, and even tactical use of electronic systems depend on a realistic understanding of the electromagnetic environment in which the systems will be operating. Unfortunately, environmental measurements of spectrum usage cannot often be made simply, because of requirements for large amounts of data needed for a reliable statistical model and because of the very detailed measurements needed to describe technical system interactions. Some of these problems can be overcome with the aid of computer-controlled measurement systems. These computer-controlled measurement systems can provide several advantages over earlier manual systems including economical measurement of massive amounts of data, real-time measurement and analysis of high-speed phenomena, and sophisticated processing of data to provide a relatively untrained operator with answers that are not otherwise obvious.

In FY-81 the Radio Spectrum Measurement System (RSMS) (fig. 1-9) continued to make measurements of spectrum occupancy for NTIA. Unlike past years, however, when measurements were made chiefly for the frequency assignment process, the measurements made this year were mainly in support of NTIA's spectrum planning process. This work was centered about providing spectrum usage data to be incorporated into the Spectrum Resource Assessments (SRA's) being done by NTIA's Spectrum Engineering and Analysis Division in Annapolis. These SRA's are concentrated studies of the current and anticipated use of a given frequency band, intended to identify particular problems or opportunities in band crowding, system incompatibilites, etc. When this function is done

Table 1-3. GMF AND NGMF ASSIGNMENTS IN THE 5650-5925 MHz BAND

| AGENCY/SERVICE | STATION CLASS | | | | | | | | | | | | NUMBER OF ASSIGNMENTS | PERCENTAGE OF ASSIGNMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LR | MR | RO | MOB | MOD | MOEA | RLS | XC | XD | XR | XT | CF | | |
| AIR FORCE | 17 | 81 | | 11 | 1 | 1 | | 1 | | | 11 | | 123 | 51.2 |
| ARMY | 13 | 14 | 16 | | | | 3 | | | 2 | 4 | | 52 | 21.6 |
| DOE | | 11 | | | | | | | | | 4 | | 15 | 6.2 |
| NAVY | 2 | 18 | | 1 | | | | 1 | | | 12 | | 34 | 14 |
| NASA | 2 | | | | | | | | | 5 | | | 7 | 2.9 |
| | | | | | | | | | | | | | | |
| NON-GOVERNMENT | | | | | | | | 1 | 6 | 2 | | 1 | 10 | 4.1 |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| NUMBER OF ASSIGNMENTS | 34 | 124 | 16 | 12 | 1 | 1 | 3 | 3 | 6 | 9 | 31 | 1 | TOTAL 240 | |
| PERCENTAGE OF ASSIGNMENTS | 14 | 51.6 | 6.7 | 5 | 0.4 | 0.4 | 1.2 | 1.2 | 2.5 | 3.7 | 12.9 | 0.4 | | |

LR - Radiolocation Land Station
MR - Mobile Radiolocation Station
RO - Radionavigation Mobile Station
MOB - Radio Beacon Mobile Station

MOD - Telecommand Mobile Station
MOEA - Aeronautical Telemetering Mobile Station
RLS - Surveillance Radar Station
XC - Experimental Contract Dev.

XD - Experimental Dev. Station
XR - Exp. Research Station
XT - Exp. Testing Station
CF - Point to Point Microwave

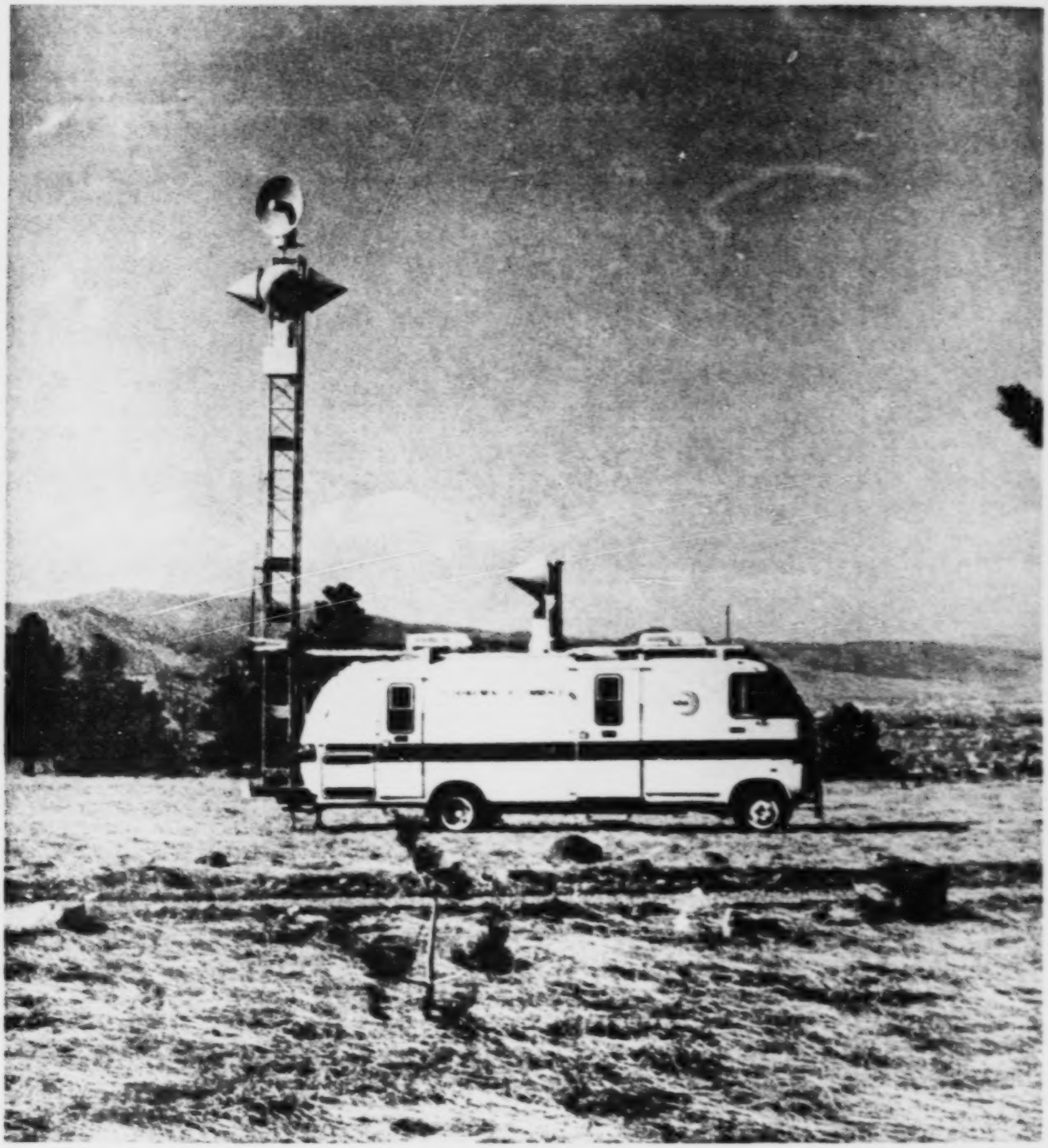


Figure 1-9. Radio Spectrum Measurement System (RSMS).

properly, frequency allocation changes can often avoid many expensive "fixes" later and can still find the required spectrum needed for many new systems. FY 81 was a particularly busy year for SRA's because of the large number of international frequency band allocation changes which came from the 1979 WARC.

Measurements were made in the Los Angeles area and in the San Diego area in FY 81. These measurements included spectrum occupancy surveys in the following bands:

162-174 MHz
216-225 MHz
225-400 MHz
406-420 MHz
420-450 MHz
902-928 MHZ
1215-1400 MHz
1660-1710 MHz
1710-1850 MHz
2200-2450 MHz
2700-3700 MHz
4400-4990 MHz
5650-5925 MHz
8500-10500 MHz

About half of these bands had not been measured by the RSMS before, necessitating a considerable amount of hardware and software development. In addition, some of the band measurements required better sensitivity than was currently available with the RSMS, which was partially solved by using bandpass filters and preamplifiers at the top of the antenna tower. In other cases, the need for still more sensitivity required the use of high-gain, directional antennas plus preamplifiers.

The largest amount of development, however, has been in the computer software measurement and analysis programs. The RSMS is a computer-controlled measurement system (fig. 1-10) designed especially to efficiently measure the large amount of data needed to characterize spectrum occupancy. While the RSMS is essentially a radio receiver which can tune to any frequency between 1 MHz and 18 GHz and which can process the received signal level in a number of ways, the actual function is determined mostly by the computer programs which are developed to control the receiving system. To better gather data for the SRA studies, a number of existing RSMS measurement programs were modified to add the following set of capabilities:

1. automatic measurement and recording of data without the presence of an operator, allowing 24 hour a day operation;

2. automatic switching between sub-bands to allow a large frequency range to be measured in several sub-bands; and

3. operator interaction permitted during measurements to give more complete control of the measurement system for identification of signals.

In addition, a series of corresponding analysis programs were produced which allowed a rapid inventorying of data files on magnetic tape, followed by accumulation of statistical data from all files meeting certain selection criteria. Another group of programs allows the data statistics to be displayed in various ways.

Figure 1-11 shows an example of the output of a measurement program called "Quick Search," which is typical of the recent measurement program developments. This program was designed to look for occasional signals in a band, ignoring measurements which do not contain signals. Measurements are made rapidly across a frequency band using simultaneous peak and average detectors (solid and dashed lines, respectively). The measurements are tested against a peak and average threshold (indicated by the two "tic" marks on the right-hand edge of the graph). If neither threshold is exceeded by the set of measurement points, the program assumes that no signal is present and discards the measurement data. The program then proceeds to measure the next frequency band on its list. If no signals are detected, the measurements require about 3 seconds per band.

If signals are seen, as in Figure 1-11, the measurement system responds with several options. An automatic direction-finding routine is employed to find the approximate bearing from which the signal came. This is done by rapidly switching between four fixed antennas in different directions and comparing the amplitude of the signal received on each of them. In Figure 1- 11, a bearing of 136° was obtained from average measurements, and a bearing of 136.9° was calculated from peak measurements. Bearing can typically be measured to within 10°. Once the direction-of-arrival of the signal has been determined, all data are recorded on magnetic tape and with paper hardcopy.

This type of scanning does a fairly efficient job of detecting the occasional unknown signal. One problem is that a large amount of data is potentially available, possibly more than is practical to consider before additional data reduction is accomplished. Editing programs are available which combine data from all data fields measured in identicial frequency bands, giving maximum, average, and minimum signal amplitudes on a single plot.

Figures1-12 and 1-13 are examples of some of the statistical occupancy summaries which are produced by the data editing progams. Figure 1-12 shows the statistics of average detector measured amplitudes. These data were collected from a total of 9814 scans across the frequency range and show the highest measured values (solid line) and the average of the measured values (dotted line). The average of the measured values includes only those data sets which contained signals above analysis thresholds. Figure 1-13 shows the same data processed differently. This graph shows the percentage of time that signals above the analysis threshold were observed. In this case, radiosonde signals near 1680 MHz were observed about 1% of the time. Similar sets of statistics are produced from the peak detector measurements.

This year, the RSMS has performed work for other government agencies on a reimbursed basis. In one case, the FAA wanted measurements made of spectrum occupancy in the 2700-3100 MHz band in the Los Angeles area. These measurements were made to provide information on the interference environment which would be encountered by NEXRAD. NEXRAD is a doppler weather radar being developed jointly by FAA,

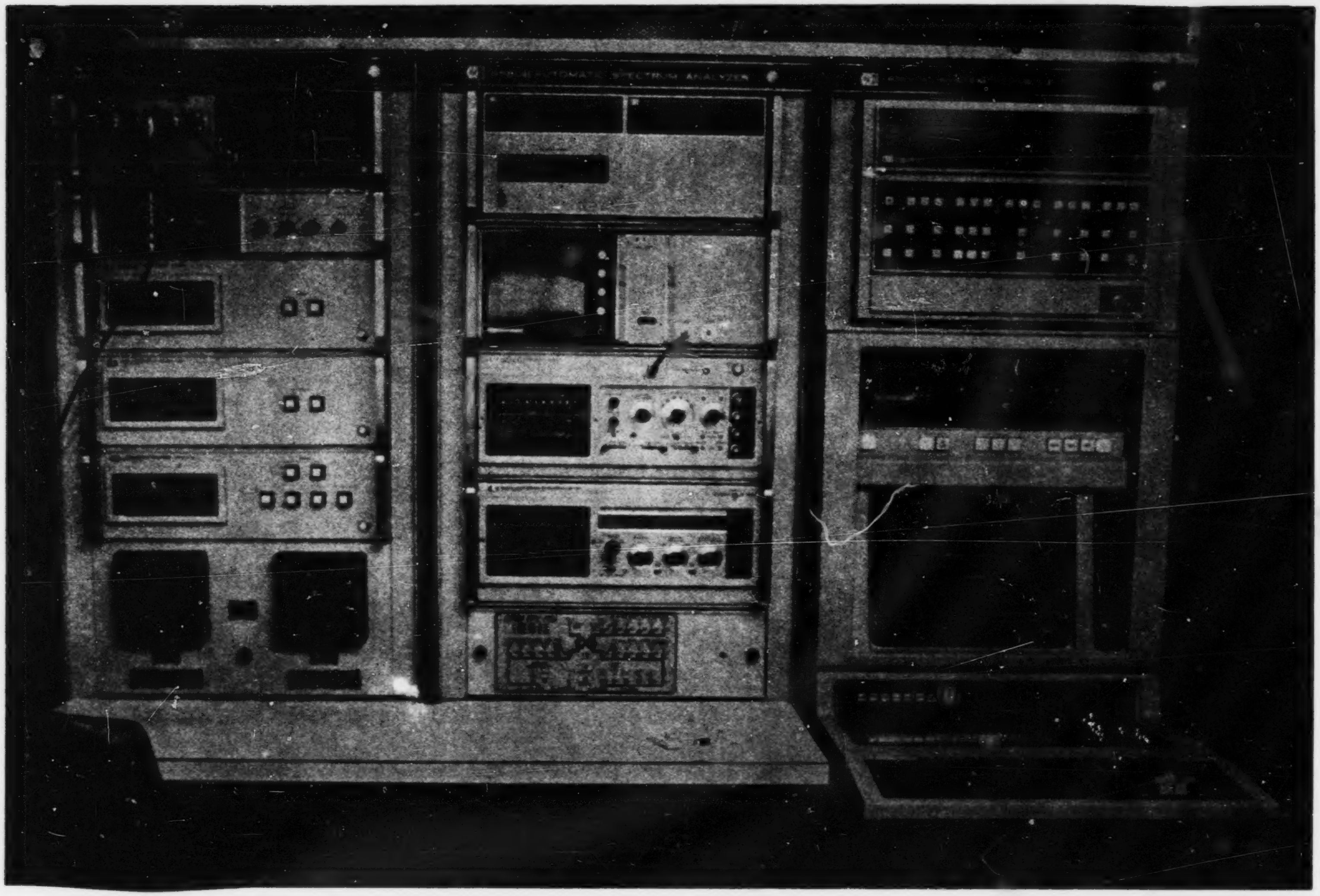
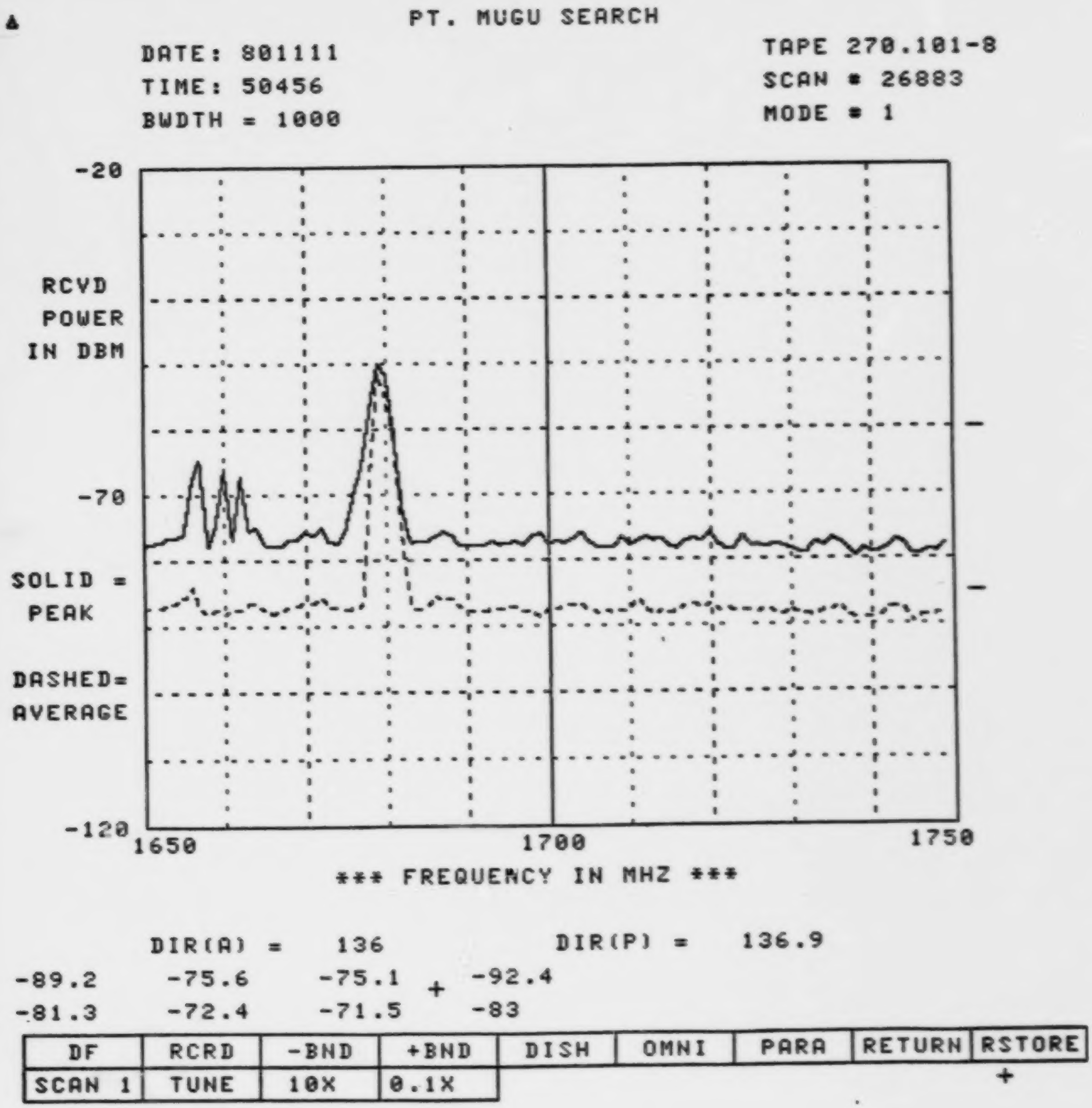


Figure 1-10. RSMS spectrum measurement equipment.



```
                    PT. MUGU SEARCH
      DATE: 801111                        TAPE 270.101-8
      TIME: 50456                         SCAN # 26883
      BWDTH = 1000                        MODE # 1
```

-20
RCVD
POWER
IN DBM
-70
SOLID =
PEAK
DASHED=
AVERAGE
-120
1650
1700
1750
*** FREQUENCY IN MHZ ***

```
        DIR(A) =    136           DIR(P) =    136.9
-89.2      -75.6      -75.1  +  -92.4
-81.3      -72.4      -71.5     -83
```

| DF | RCRD | -BND | +BND | DISH | OMNI | PARA | RETURN | RSTORE |
|---|---|---|---|---|---|---|---|---|
| SCAN 1 | TUNE | 10X | 0.1X | | | | | + |

Figure 1-11. Example of Quick Search data.

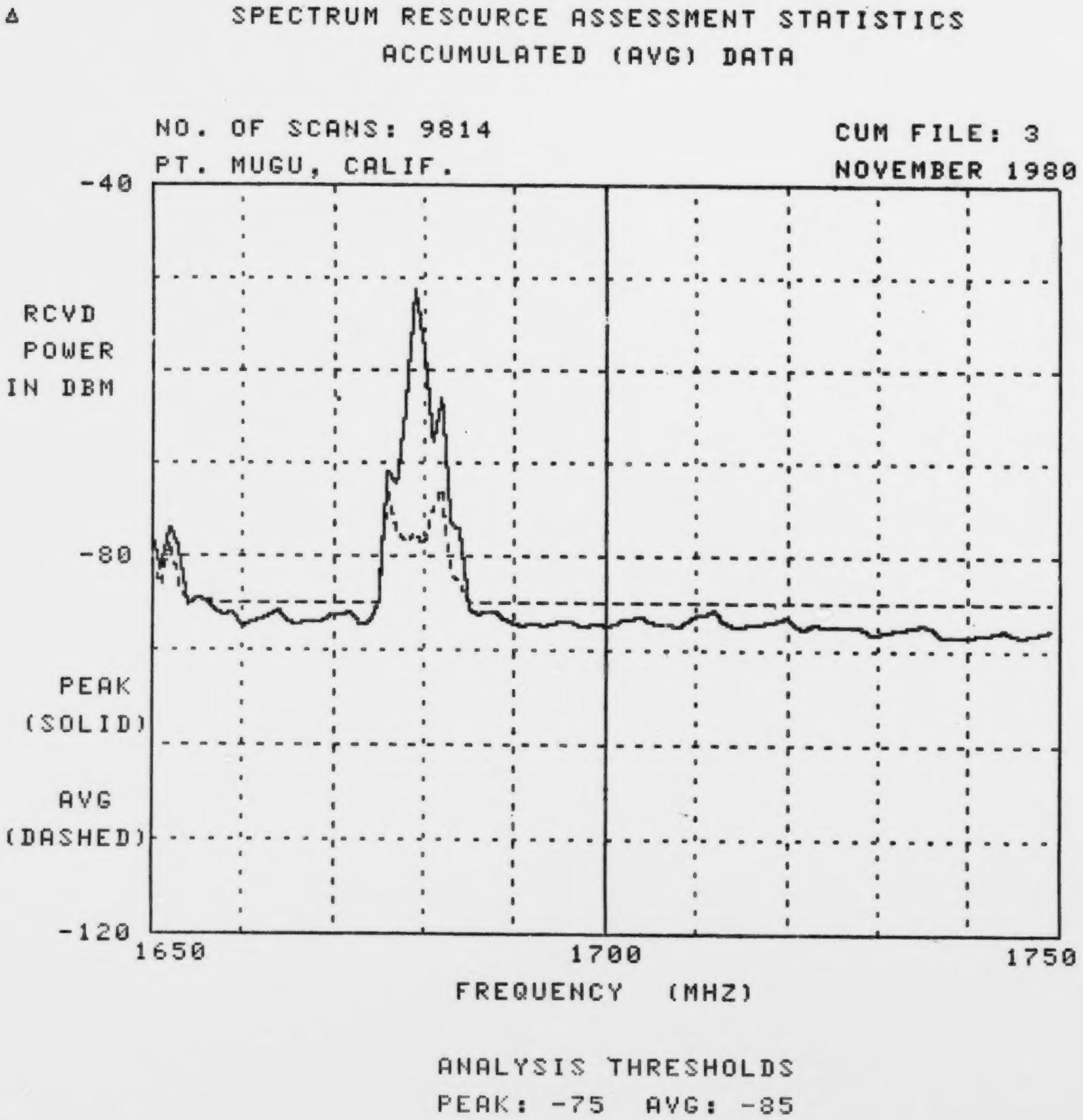


Figure 1-12. Statistical amplitude graph, average detector data.

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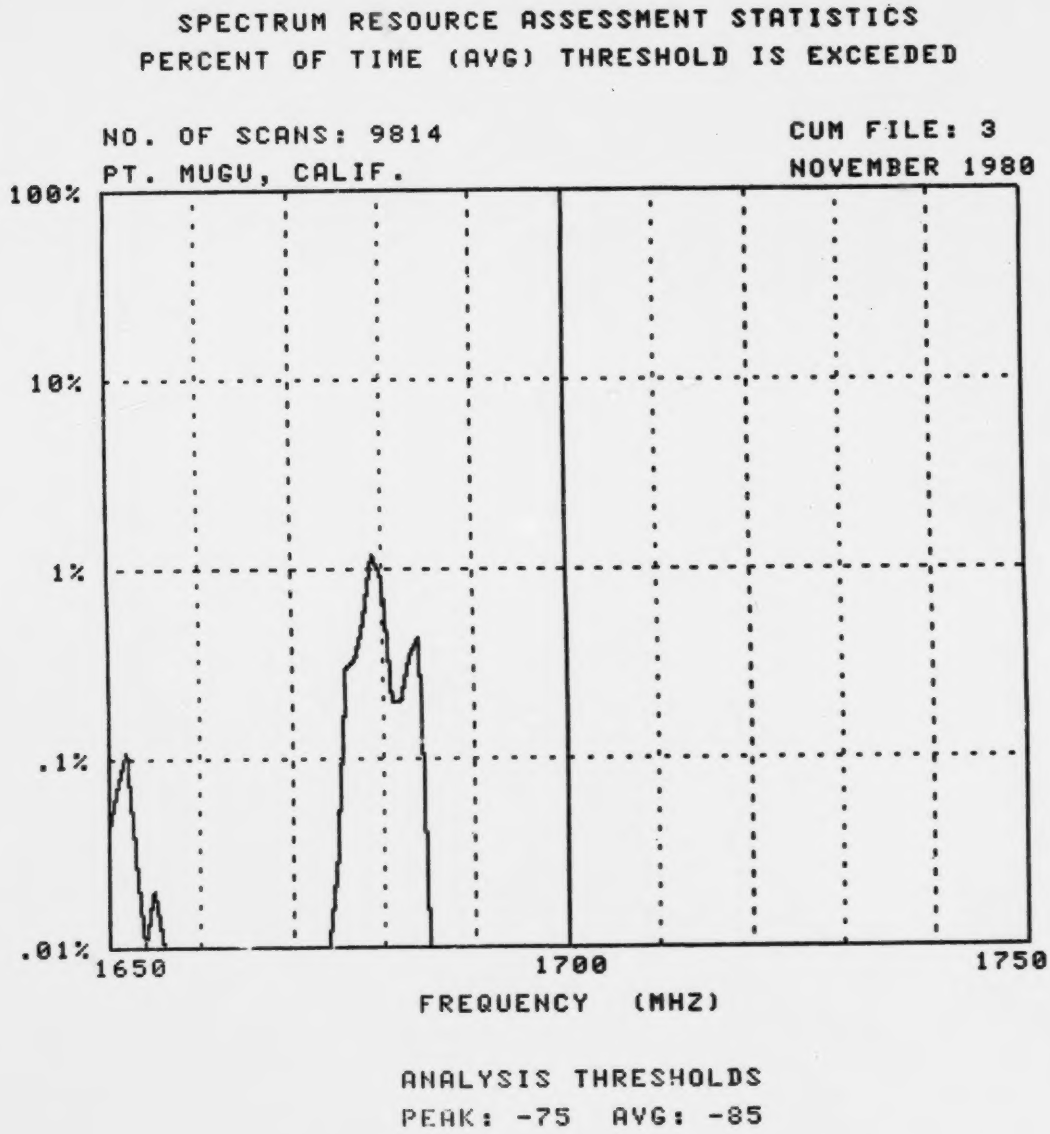


Figure 1-13. Statistical occupancy summary, average detector data.

the Air Force, and NWS, and is expected to bring greatly improved reliability for warning of severe storms. The expected interference environment may determine the feasability of putting NEXRAD in these frequency bands and will certainly affect the amount of signal processing incorporated in the NEXRAD design.

To provide a sufficient level of detail in these spectrum occupancy measurements, it was decided to make several types of measurements from two sites in the Los Angeles area. The two sites were mountaintop locations near San Pedro and Whittier, both of which were selected as possible NEXRAD sites experiencing high levels of potential interference from other radars in the frequency band. At each site, measurements were made for several days on a 24-hour basis, which included substantial periods of unattended operation. When operators were present, radars could be identified by their pulse characteristics and by the apparent signal direction of arrival. Measurement data were recorded on paper hardcopy for immediate analysis and on magnetic tape for later statistical analysis.

The measurements consisted of two major types. Peak amplitude data was measured across the frequency band, as shown in Figure 1-14. This measurement is similar to measurements of band occupancy made earlier by the RSMS. It plots peak power received in a 5 second period vs. frequency. A 5 second dwell time is spent at each frequency to allow a typical radar in the band time to rotate once. If the dwell period is chosen to be at least as long as a radar antenna rotation period, the radar will point directly at the RSMS at least once during the measurement period. When the dwell period has been finished at one frequency, the measurement system tunes to the next higher frequency and continues. When the entire frequency band has been measured, the graph is copied, data is recorded on magnetic tape, and the program continues measurements at the next portion of the frequency band.

In addition to the peak amplitude measurements described above, the number of pulses exceeding three amplitude levels were counted. The three amplitude levels are graphed as short "tic" marks at the right hand edge of Figure 1-14. This allows the operator to manually adjust the thresholds, watching the position of the tic marks, until he has the desired setting. Figure 1-15 shows a graph of the number of pulses measured simultaneously with the data in Figure 1-14. The counts graphed are the counts measured over a 5 second dwell period at each fequency; the counts must be divided by 5 to get the average number of pulses per second. The graph is generated, copied, and recorded on magnetic tape immediately following the copying of the amplitude graph. For this series of measurements, the thresholds were nominally set at -90 dBm, -70 dBm, and -50 dBm. The count data from each of those three thresholds were plotted using a dotted, solid, and dashed line for each count level, respectively.

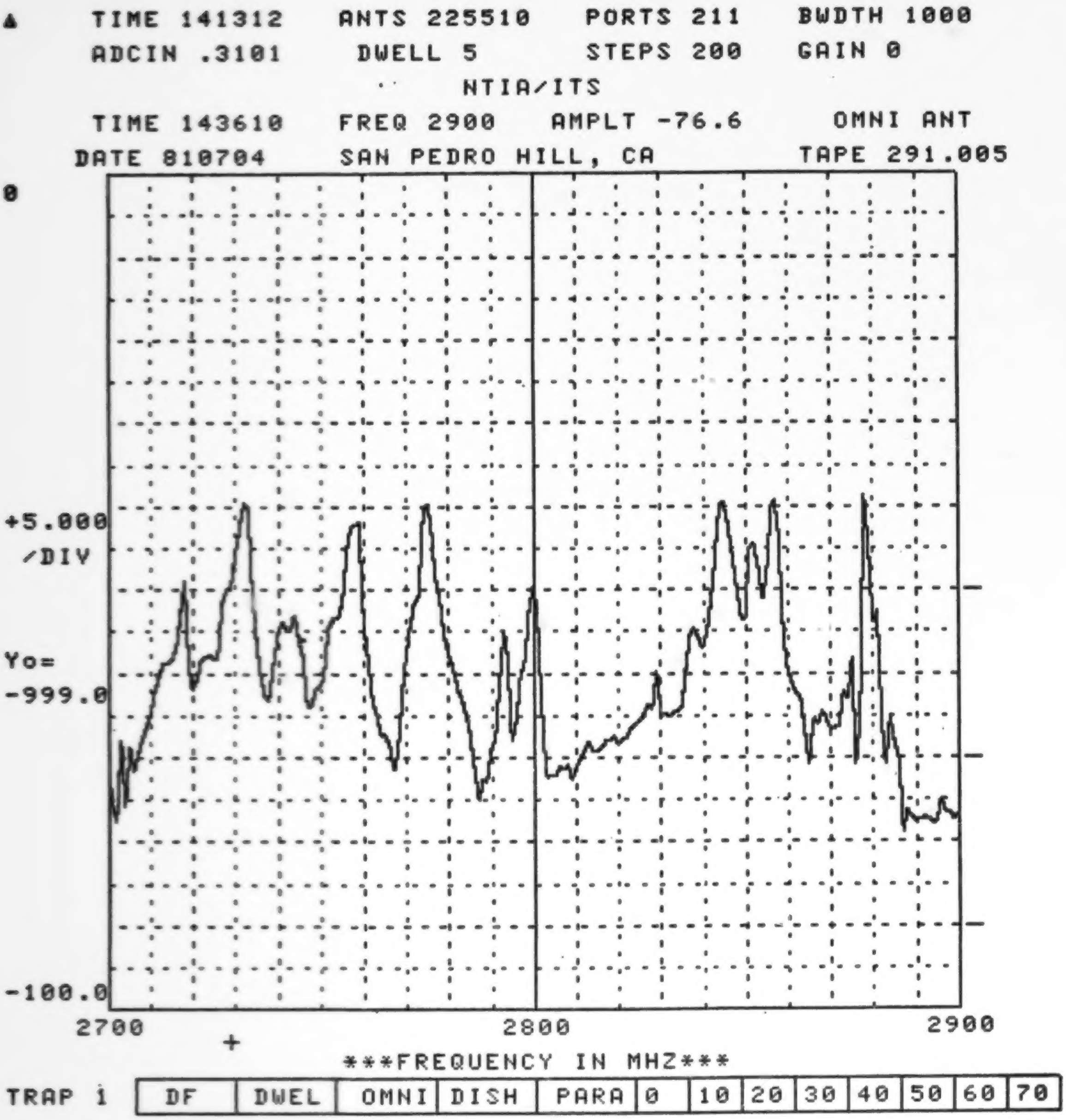
The measurement program described above was run more or less continuously, giving approximately 500 sets of amplitude and count data in about 165 hours of measurements divided between two sites in a 2-week period. After the measurements were finished, the data on magnetic tape were analyzed to give statistical summaries of the data measured at each site. Figure 1-16 is a statistical summary of all the amplitude data recorded on tape at the San Pedro site. On this plot, the maximum amplitudes and the minimum amplitudes from the individual graphs for each frequency are plotted with a solid line; the average amplitude is plotted with a dashed line. Note that many more radars than normal show up on the statistical amplitude analysis because many radars are operated intermittently, but only a portion of the intermittant radars are likely to be operating at a given time. A set of 3 pulse count graphs are produced by the statistical analysis programs, one for each threshold level. Figure 1-17 shows the corresponding graph for threshold level B (-70 dBm). Again, the maximum and minimum levels are plotted with a solid line and the average level is plotted with a dashed line.

This work was particularly valuable to us in several respects. The work provided a technique for obtaining substantially more detailed data on spectrum occupancy, applicable to other measurements and expected to be utilized heavily for other RSMS measurements. These more detailed measurements were made with simple threshold detectors and counters, assembled quickly for this test. In spite of the simplicity of the added equipment, it is fully automatic and integrated completely into system measurement and calibration routines.

MSR-T1 MULTIPLE RECEIVER SYSTEM AND SD-2R ECM RECEIVER. The AN/MSR-() is a transportable, automatic multiple receiver system that is to be employed by the Air Force at various electronic warfare (EW) ranges for determining the operational readiness of fleet aircraft and aircrews to perform electronic countermeasures (ECM) during strategic and tactical missions. The Institite for Telecommunication Sciences was tasked by the Air Force Systems Command (AFSC) to develop, design and test a prototype model of the AN/MSR-() which would serve as a basic for the production procurement of similar models. This task was completed in 1980, and AFSC requested that ITS provide follow-on technical support during the production-procurement cycle.

In support of this program, ITS prepared detailed technical specifications which included hardware/software performance criteria and functional requirements for the Air Force to use as a Request for Proposal from industry. Five responses were received and ITS played a key role in their technical evaluation. A contract award, based on technical considerations, was made to Martin-Marietta Aerospace, Denver Division, in April 1981, for the production of 7 systems.

The AN/MSR-() units consist of 0.03-18 GHz multiple receivers, antennas, and signal processors which are interfaced to and controlled by a central computer unit and, while conceptually similar to the prototype model, are less complex, more versatile, and have increased capabilities. Complexity was reduced by the use of real-time data acquisition and analysis schemes which required less hardware (recei-



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▲    TIME 141312    ANTS 225510    PORTS 211    BWDTH 1000
     ADCIN .3101     DWELL 5       STEPS 200    GAIN 0
                         NTIA/ITS
     TIME 143610    FREQ 2900    AMPLT -76.6       OMNI ANT
    DATE 810704    SAN PEDRO HILL, CA           TAPE 291.005
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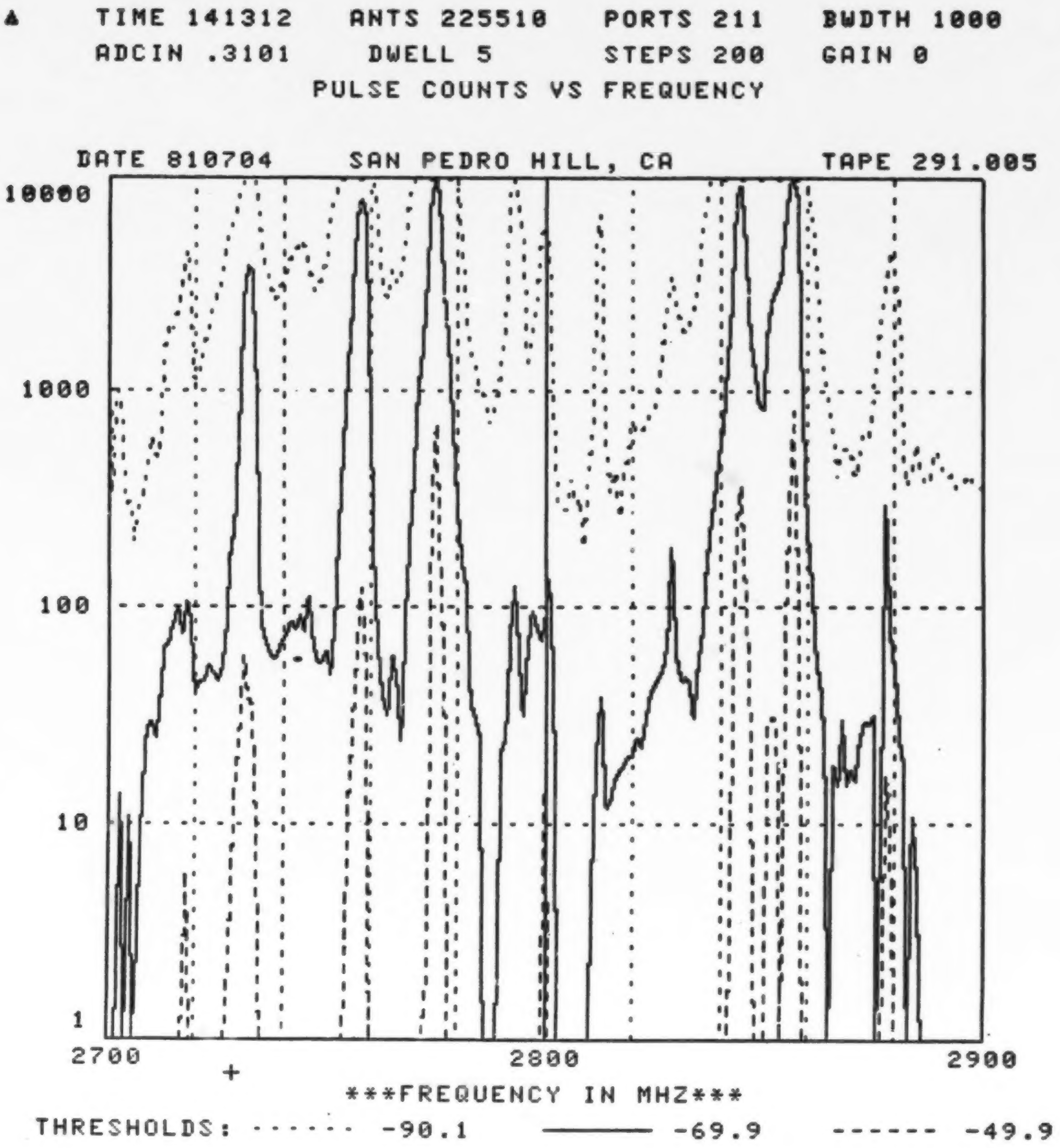
Figure 1-14. Single measurement of peak amplitude versus frequency.



A TIME 141312 ANTS 225510 PORTS 211 BWDTH 1000
ADCIN .3101 DWELL 5 STEPS 200 GAIN 0
PULSE COUNTS VS FREQUENCY

DATE 810704 SAN PEDRO HILL, CA TAPE 291.005

THRESHOLDS: ------ -90.1 ——— -69.9 ------ -49.9

Figure 1-15. Single measurement of number of pulses versus frequency.

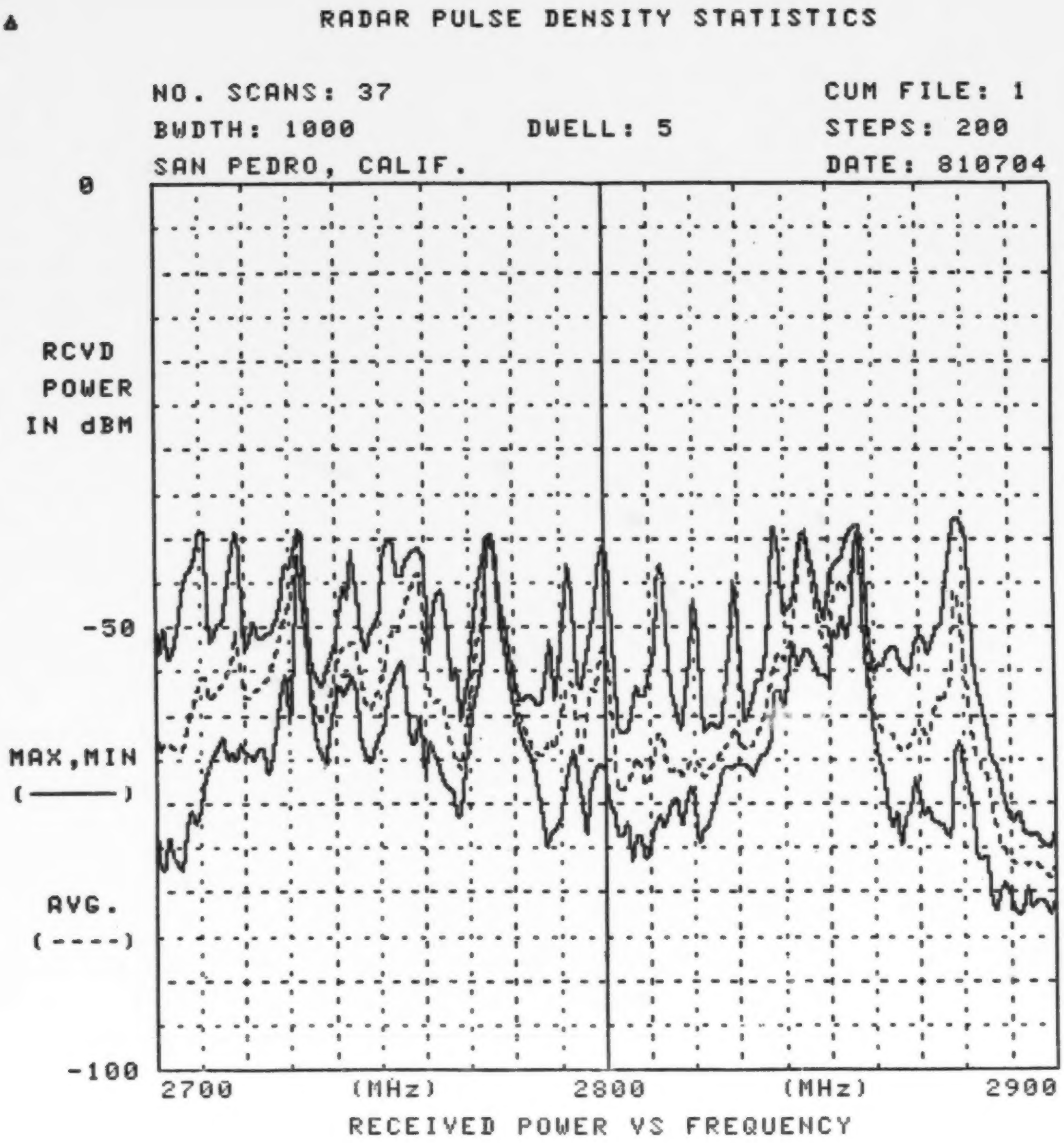


Figure 1-16. Statistics of peak amplitude versus frequency.

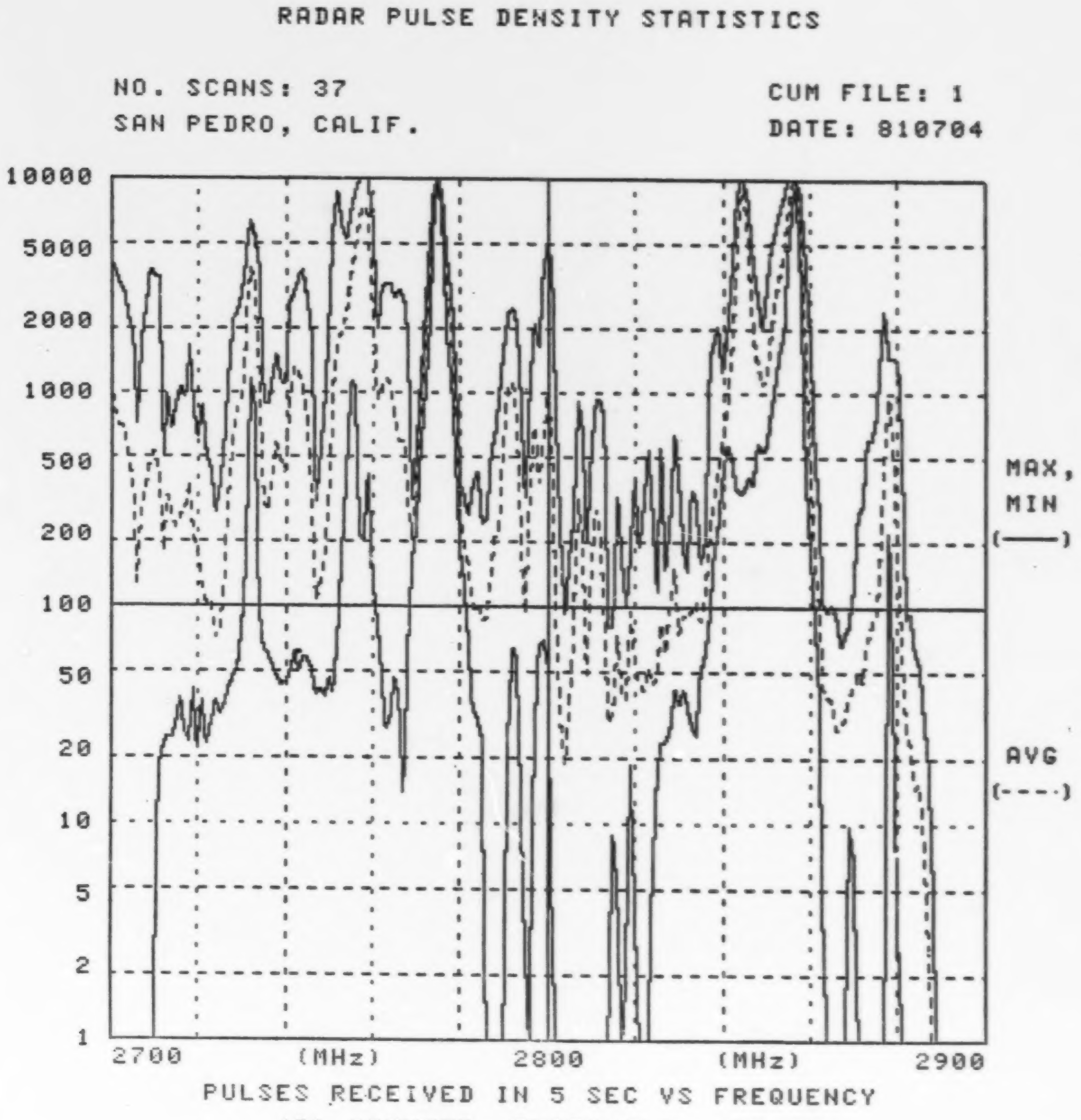


Figure 1-17. Statistics of number of pulses exceeding -70 dBm.

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vers/signal processors). Versatility was increased via software/firmware improvements and the use of time sharing schemes from "lessons learned" in deployment and use of the prototype model. The capability is increased with the addition of an autonomous automatic IFF target tracking subsystem (also added to the prototype) and automatic pulse blanking with a variable range gate tracking window around the airborne target of interest. These capabilities were added to improve compatibility of operations when the system is located at or near the high power groundbased threat radars and reduce multipath interference during airborne ECM emission reception and analysis.

Features of the prototype design which proved operationally effective were retained. For example, the automatic antenna switching and signal conditioning matrix which provides for the simultaneous reception of multiple rf signals and the automatic system performance verification subsystem were retained with design improvements and incorporated in the production units. Operator interaction has been reduced to essentially a monitoring function, but intervention is permitted via simplified keyboard entries if unusual events occur that require special tailoring of the equipment resources and software control functions.

As follow-on support during the Air Force procurement-production cycle, ITS has provided technical guidance during Preliminary and Critical Design Reviews at the Contractor's facility. This involved two principal tasks: (a) review and (b) prepare and document detailed technical descriptions of all Air Force operational airborne ECM systems and groundbased threat radar systems. The latter information establishes the data base used by the AN/MSR-() to verify operational readiness of the ECM systems to perform their intended jamming/deception functions during the conduct of EW tests and exercises.

A typical EW test or exercise may only last for a few minutes (3-8) of time while a strategic or tactical mission is underway and will normally involve 8 to 10 different ground based threat radars operating at various frequencies over a broad rf spectrum. Each radar signal is a potential threat to the aircraft's mission, and its on-board ECM system (or multiple systems) will respond with a countermeasure signal to deceive or disrupt the radars' acquistion or tracking circuits. Thus, the AN/MSR-() must react to this changing and dynamic electromagnetic environment and collect, analyze, and output specific characteristics/parameters of all countermeasurer responses to assess operational readiness. Identification and diagnosis of airborne, inflight malfunctioning ECM systems are the primary functional requirments of the AN/MSR-().

Phase III of the Southern California Propagation Study was completed this year. The project objectives are to develop plans for the measurement of VHF and UHF propagation loss, particularly under ducting conditions and to design, fabricate, and install automated special purpose propagation measurement and data acquisition equipment. Design was completed and four automatic propagation measurement systems were built and three were deployed in the San Diego area. Each of the systems will measure ten signals in the frequency range of 60 to 900 MHz for about one and one-half years. The systems, being microprocessor controlled, proceed through an hourly cycle of self-calibration, sequential data collection, and data analysis and storage. Data summaries are printed locally, and all raw data along with the summaries and overhead information are recorded on magnetic tape. The Federal Communications Commission will collect the data tapes once per month for further analysis. The ultimate goal of the project is to develop statistics on the incidence of ducting propagation conditions at VHF and UHF in the Southern California environment.

Phase I of this project provided the FCC with an overview of the propagation phenomena involved, recommendations as to the type and amount of data needed to accomplish the overall project objectives, and descriptions and cost estimates of the equipment needed. In consultation with the FCC staff, the Institute for Telecommunication Sciences has provided the FCC with the following specific items of information:

(1) a review of the propagation phenomena involved that is based on available theoretical and empirical studies and interference reports;

(2) recommendations as to paths, recording sites, and transmitting sites required to obtain needed data;

(3) recommendations as to signal sources;

(4) recommendations as to desirable data sampling rates, amount of on-site data reduction, and statistical parameters to be recorded for reduced data; and

(5) recommendations as to meterological data needed and sources.

This information was presented in an informal report to the FCC, entitled "Planning for the Measurement of Propagation Phenomena in Land Mobile Frequecy Bands in Southern California," dated June 2, 1980.

The objective of Phase II was to develop the design of both the receiver and the receiver control/data collection system (RCDCS) to the point where the procurement of supplies and equipment could begin and then to procure some of those supplies and equipment.

Figures 1-18 and 1-19 are block diagrams of the receiver and the RCDCS, respectively. Figure 1-20 is a photograph of the entire propagation measurement system.

The receiver is composed of a mainframe with five modules, along with peripheral components, the antennas, and local oscillator.

The receiver design philosophy included very reliable operation over a long period of time and assurance of the quality of the measured data. Accordingly, several departures were made from conventional receiver design. Mechanical switches were avoided whenever possible; very large instantaneous dynamic range

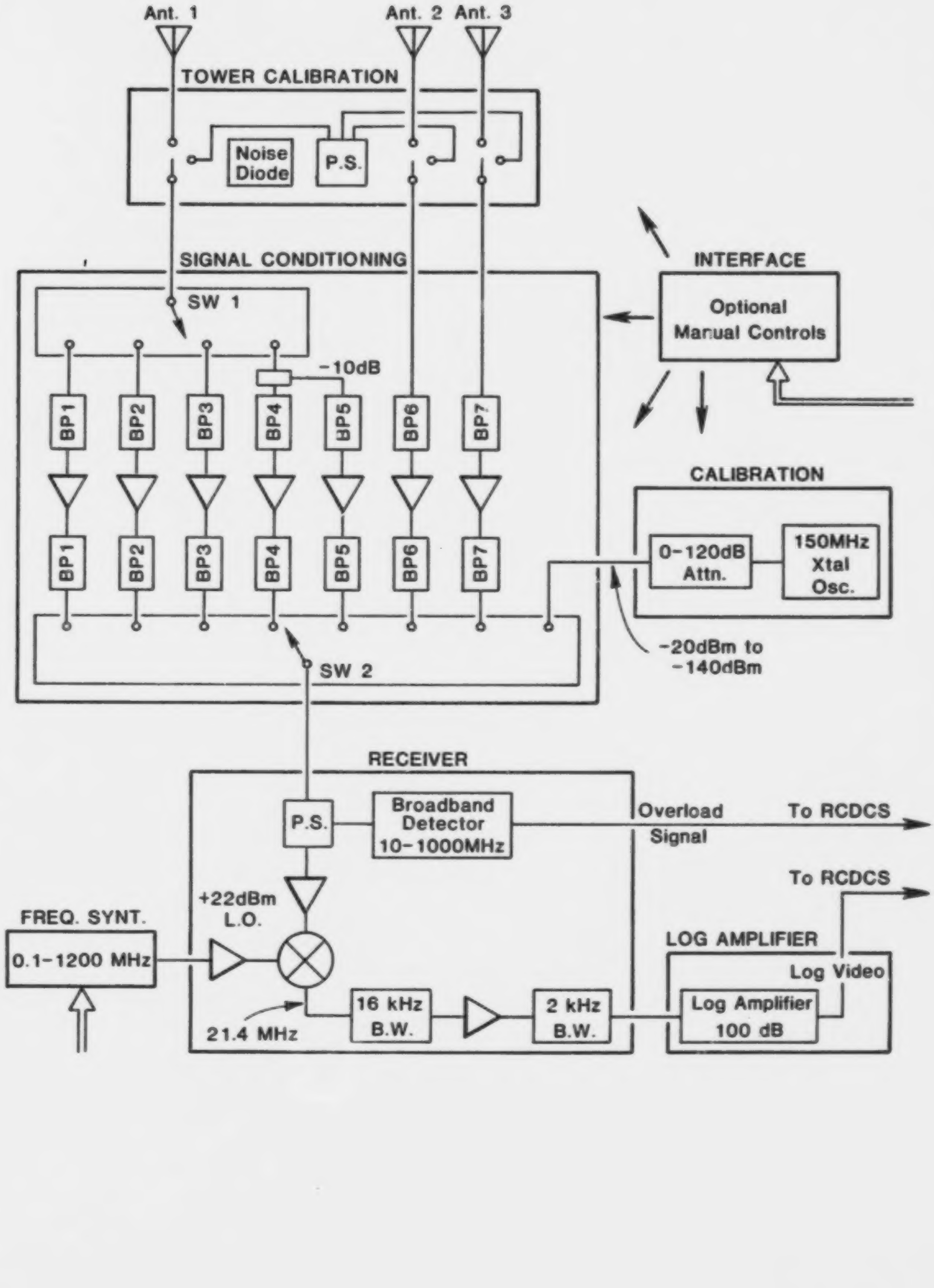

Ant. 1
Ant. 2
Ant. 3
TOWER CALIBRATION
Noise Diode
P.S.
SIGNAL CONDITIONING
SW 1
-10dB
BP1
BP2
BP3
BP4
BP5
BP6
BP7
SW 2
INTERFACE
Optional Manual Controls
CALIBRATION
0-120dB Attn.
150MHz Xtal Osc.
-20dBm to -140dBm
RECEIVER
P.S.
Broadband Detector 10-1000MHz
Overload Signal
To RCDCS
To RCDCS
+22dBm L.O.
FREQ. SYNT.
0.1-1200 MHz
LOG AMPLIFIER
Log Video
Log Amplifier 100 dB
16 kHz B.W.
2 kHz B.W.
21.4 MHz

Figure 1-18. Propagation measurement receiver block diagram for the Southern California Propagation Study.

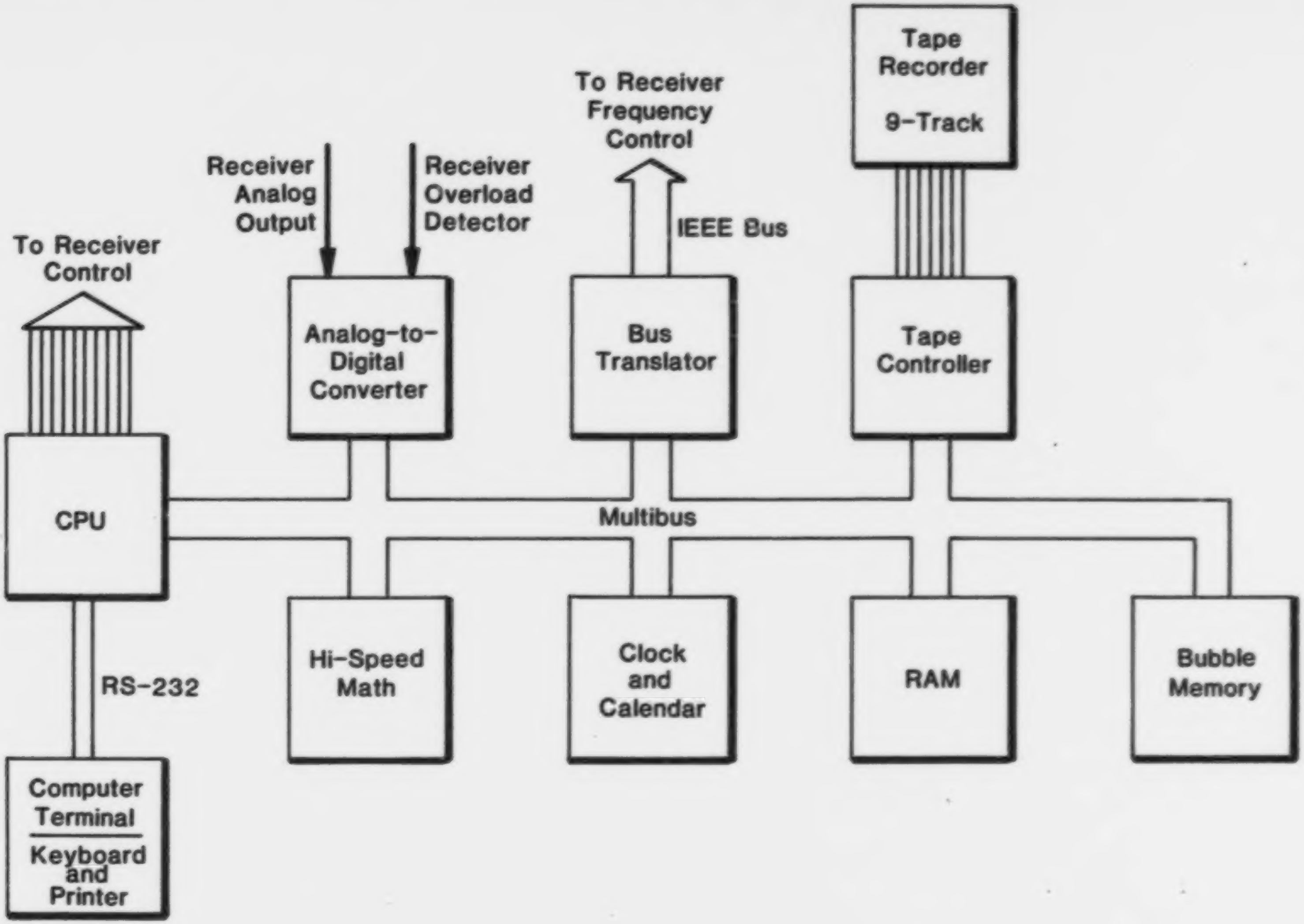

Tape Recorder
9-Track
To Receiver Frequency Control
Receiver Analog Output
Receiver Overload Detector
IEEE Bus
To Receiver Control
Analog-to-Digital Converter
Bus Translator
Tape Controller
CPU
Multibus
RS-232
Hi-Speed Math
Clock and Calendar
RAM
Bubble Memory
Computer Terminal
Keyboard and Printer

Figure 1-19. Block diagram of the receiver control/data collection system (RCDCS) for the Southern California Propagation Study.

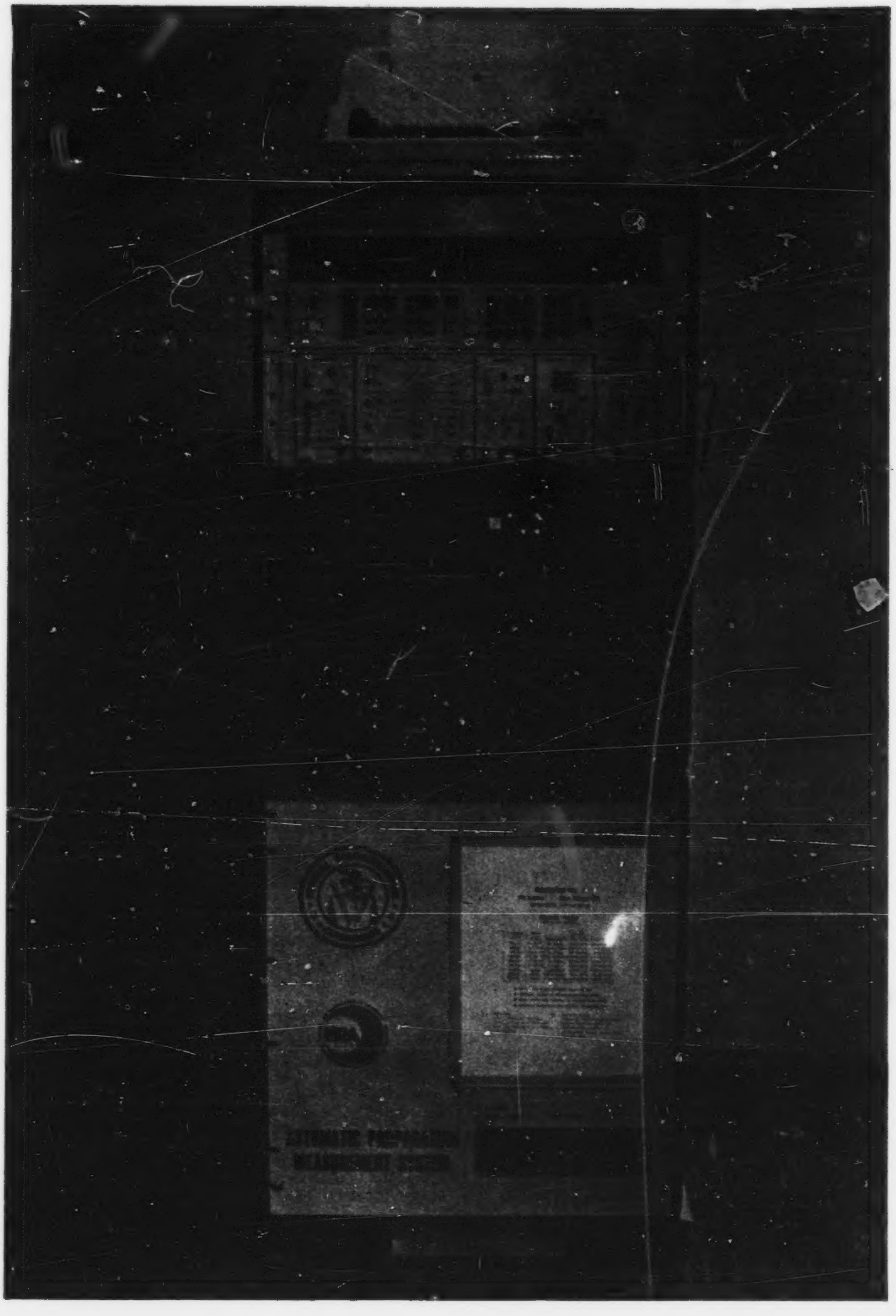

AUTOMATIC PROPAGATION
MEASUREMENT SYSTEM

Figure 1-20. The Automatic Propagation Measurement System for the Southern California Propagation Study.

(about 95 dB) avoids the need for switched attenuators and provides considerable tolerance to large signals. High level mixing and sensing of very large signals helps to avoid the possibility of spurious intermodulation products producing incorrect measurement results. Finally, hourly calibration will correct any minor changes in the receiver characteristics.

The propagation measurement receiver is mostly contained in five modules, plugged into a mainframe with power supplies and interconnections, as shown in Figure 1-20. The signal conditioning module contains two signal distribution switches and up to seven bandpass filters and preamplifiers. One antenna connection can be switched to as many as five bandpass filter channels via SW 1, a mercury-wetted four-position relay. This switch offers a very long operational lifetime and is immune to intermodulation products which might be caused by high amplitude signals. A second switch, SW 2, utilizes PIN-diodes to provide electonic switching. The function of this module is to select the signals to be recovered, while isolating the receiver from large out-of-band signals.

The receiver module mixes the selected rf signal down to 21.4 MHz in a 3 kHz bandwidth. Very high-level mixing is employed (+22 dBm local oscillator) to minimize spurious responses. The 2 kHz IF bandwidth further reduces responses from close-in signals and permits good receiver sensitivity. Finally, a broadband detector measures any large signal in the bandpass and prevents data from being processed if there is the likelihood of spurious intermodulation products being mistaken for the intended signal. The amplified output of a laboratory frequency synthesizer is used to tune the local oscillator to exactly the correct frequency.

The log amplifier module converts the 21.4 MHz IF signal to a dc value over a 95 dB range of input signal. This module also contains an audio amplifier and loudspeaker for aural monitoring of the receiver signal.

During the receiver calibration cycle, two calibration sources are employed. A calibration module in the mainframe provides a 150 MHz calibration signal used to linearize the logarithmic amplifier response. A broadband noise diode is used to provide an absolute calibration of received signal in 10 dB steps between -140 dBm and -20 dBm. This calibration signal is used to linearize the logarithmic amplifier response. A broadband noise diode is used to provide an absolute calibration of received signal amplitude. Since the noise diode calibration signal is inserted into the system at the top of the antenna tower, the process calibrates the entire receiving system, including any transmission line losses between the antennas and the receiver.

The interface module acts as an interface between the microprocessor and the receiver, as well as permitting manual control of the receiver. Because of the importance of knowing when the receiver is not entirely under automatic control, logic built into the system permits manual control only when "permission" is given by the microprocessor. In addition, the microprocessor is notified if any module is unplugged from the mainframe or if the tower calibration box is disconnected from the mainframe.

The two purposes of the RCDS are evident in its name: (1) to control the receiver by providing signals to switch antennas, filters, and oscillators and (2) to digitize the receiver output and to manipulate and record the data.

The block diagram in Figure 1-19 shows the major hardware components and their relationships to each other and the receiver. The system communicates internally by way of the multibus. The system as configured is tailored to the desired measurements but is extemely flexible and is easy to modify for other requirements. With the exception of the advanced analog-to-digital (A/D) converter and the terminal, we have experienced excellent reliability with similar systems and configurations. The A/D and terminal, moreover, are improvements of similar devices that we have used in the past and to add to reliability.

Referring to the block diagram of Figure 1-19, the central processor (CPU) is contained on one board. It controls the multibus, performs or directs calculations, and controls all peripher 1 equipment. The 21 transistor transistor logic lines used to control the receiver directly from the CPU consist of 7 for calibration control and 16 for antenna and preselector control.

The computer terminal permits communication with the CPU and provides any necessary hard copy printout in the field. It is capable of 1200 baud printing speed.

The hardware math board will perform most of the calculations. This will speed up the operation of the system as a whole and allows more memory to be used for user programs.

The clock/calendar board is used to provide the time and date along with the data being recorded.

There are two memory boards in the system. The RAM board has 48 k bytes of high-speed RAM that together with the 16 k bytes on the CPU board provides 64 k bytes of RAM for the system. The bubble memory board has 125 k bytes of non-volatile memory which is used primarily for program storage.

The A/D board will accept the analog information from the receiver's log-amplifier and overload detector circuit, then digitize these for processing and recording.

The last two boards are bus translator and tape controller boards. These provide an interface to two peripherals. The former converts multibus codes into IEEE bus codes. The IEEE bus is needed to properly communicate with the synthesizer, which controls the frequency of the receiver. The latter supplies formatting and interface signals to the digital tape recorder. This interface board is capable of direct memory access and allows record lengths up to 4096 bytes.

Another major portion of Phase III involved the examination of the possible receiver sites and assistance to the FCC in choosing receiver sites and sources for measurement. The three sites chosen for the propagation measurement system are:

Site 1. Point Loma
- on Naval Ocean Systems Center property,
- 32°40'03"N, 117°14'36"W, 15 m/msl (above mean sea level),
- very close (100-200 m) to the Pacific shore.

Site 2. La Mesa
- on the premises of the FCC field office in La Mesa,
- 32°46'08"N, 117°01'43"W, 150 m/msl,
- about 15 km inland from the shore.

Site 3. Cowles Mountain
- at the "head-end" of a cable TV company,
- 32°48'45"N, 117°01'50"W, 475 m/msl,
- about 20 km inland from the shore.

The choice of signals to be monitored at each location took into account a variety of path characteristics and, of course, the availability of signal sources. Table 1-4, below, gives only the frequencies of the sources to be received at each of the three receiver sites. These sources are of two types: television signals (only the video carrier is measured) and test signals installed for this experiment. The last three sources listed in the Table are the test sources. Nearly all of the sources are located in the Los Angeles area.

Table 1-4. Receiver Site Measurement Frequencies

| Site 1 (MHz) | Site2 (MHz) | Site 3 (MHz) |
|---|---|---|
| 61.25 | 741.25 | 61.25 |
| 175.25 | 175/25 | 175.25 |
| 497.25 | 519.25 | 519.25 |
| 735.25 | 735.25 | 735.25 |
| 531.25 | 531.25 | 531.25 |
| 687.25 | 687.25* | 687.25 |
| 741.25 | 687.25* | 487.25 |
| 418.00 | 418.00 | 418.00 |
| 869.00 | 869.00 | 869.00 |
| 869.50 | 869.50 | 869.50 |

*This signal will be received using both horizontal and vertical polarization.

The other important path parameters associated with this selection of sources and receiver sites are: terrain type, source height, and path length. Of the paths chosen, some are almost entirely over water or land (several each); most are a combination of land and water. The source height ranges from 20 m/msl to over 1800 m/msl. The path length ranges from as low as 15 km (one case), to a typical value of about 150 km, to as high as 330 km.

The DM-4 is an instrument developed at ITS to measure impulsive noise and other wide-dynamic range statistical events. It measures the amplitude probability distribution of noise by determining the percentage of time that the noise exceeds the level of 31 threshold amplitudes. The original DM-4 is shown in Figure 1-21. Other features of the DM-4 include internal microprocessor control and an IEEE 488 instrument interface, sampling rates between 1 kHz and 20 MHz, video bandwidths up to 10 MHz, and a number of diagnostic aids to assist the operator in verifying the quality of the noise measurements.

The DM-4 Operational Development project continued at ITS this year. Several changes to the original DM-4 design are currently underway, including the ability to operate with input signals at 455 kHz and 21.4 MHz IF frequencies (as well as the logarithmically compressed video signals used in the original version). Calibration, measurement, and data analysis software are now being adapted a desktop calculator. The change was made to allow easy previewing of measured data on the graphics tube of the calculator before recording data on magnetic tape cartridges.

The objective of the Earth Terminal Antenna Measurements project is the measurement of the magnitude of side-lobes produced by a specific 40 foot diameter antenna.

This antenna is to be installed at the Table Mountain test site where an aircraft will be used to provide the necessary elevation angles for pattern measurements above the horizontal plane.

The scheduled antenna installation date is September 30, 1981, and during FY 82 we expect to make the required measurements.

The Federal Aviation Administration's flight inspection aircraft can be equipped for a variety of missions; among these is the airborne measurement of radio signals. The purpose of the current FAA Aircraft Calibration project at ITS is to develop the calibration constant for a particular antenna mounted on this plane at the specific frequency of 100 kHz.

The aircraft calibration is a part of a larger study being conducted by the FAA - an evaluation of the effects of power line carrier (PLC) systems on airborne Loran-C receivers. The Loran-C navigation system is being considered as a supplement to and a possible replacement for the VORTAC navigation system. Loran-C signals are centered on 100 kHz with 99% of the energy confined between 90 and 110 kHz.

The PLC systems, which are operated by the electric power utilities for teleprotection, telecontrol, and other telecommunications, typically operate in the frequency range from 10 to 535 kHz. The PLC signals are not intended to radiate since they propagate along the power lines as guided waves. In practice, because real power lines contain various departures from an ideal geometry, some of the guided signals can be launched as some other mode of propagation. There is some controversy as to how, or even if, this happens. At any rate, radio-frequency signals appear to exist in the airspace above the power lines that carry PLC signals.

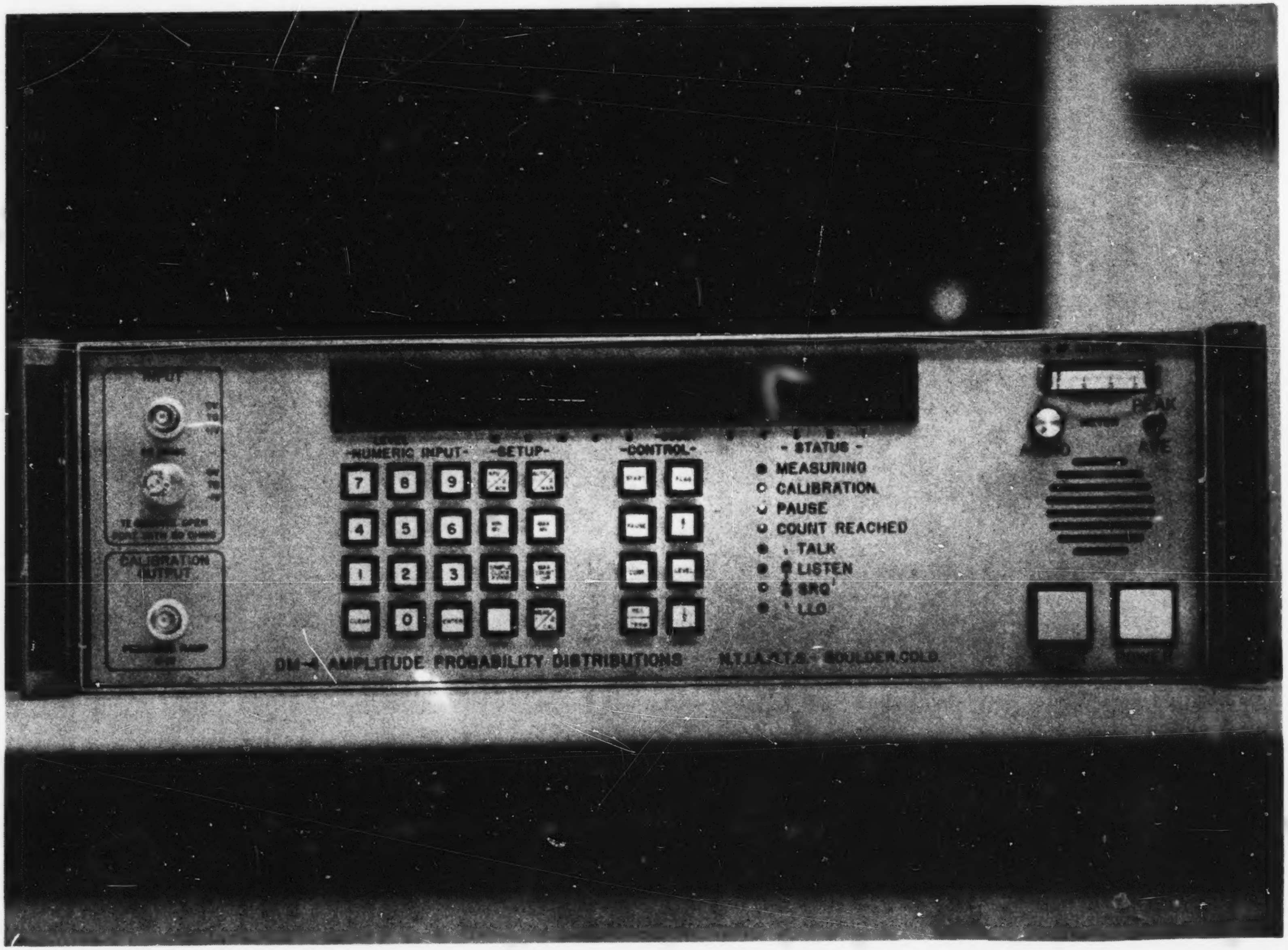

INPUT
CALIBRATION OUTPUT
-NUMERIC INPUT-
-SETUP-
-CONTROL-
- STATUS -
7
8
9
4
5
6
1
2
3
0
MEASURING
CALIBRATION
PAUSE
COUNT REACHED
TALK
LISTEN
SRQ
LLO
PEAK
AVE
DM-4 AMPLITUDE PROBABILITY DISTRIBUTIONS
N.T.I.A./I.T.S. - BOULDER, COLO.

Figure 1-21. Front panel of the DM-4.

Since the FAA aircraft is being used in several experiments designed to measure the effects of PLC signals on a variety of Loran-C receivers, it is necessary to know the calibration constant (or antenna factor) of the aircraft antenna. This is so that the received signal level (in volts) at the aircraft antenna terminals can be related to the field strength (in volts/meter) external to the aircraft. Knowing the actual field strength of the Loran and/or PLC signals makes it possible to compare the planned measurements with those made by others.

The measurement aircraft with its receiving antenna must be calibrated as a unit, because at Loran-C frequencies (90-110 kHz) even the aircraft is quite small relative to a wavelength (about 3 km). In order to perform the calibration, the plane must be immersed in a known field; therefore, the field must originate from a calibrated source.

Since this aircraft calibration must be done at 100 kHz, it is not possible to use a test source because it could interfere with Loran-C navigation equipment in use. A Loran-C transmitter is the most likely and practical source. The effective radiated power (ERP) or the field strength at some distance must be accurately determined, and the pulsed nature of the signal format must be assessed. Another requirement of the calibration measurements is that they must be made over a smooth, homogeneous surface so that reliable predictions of field strength can be made. The use of an actual Loran-C transmitter located very near the sea would satisfy this requirement.

The U.S. Coast Guard, which is responsible for the operation of the Loran-C navigation system in the United States, operates the Loran Receiver Test Complex (LRTC) in Wildwood, NJ. The most important part of the LRTC is a calibrated Loran-C transmitting station which can be put on the air whenever it is needed. It is the fifth secondary in the Northeast U.S. chain when it is on. This means that it transmits a group of eight pulses in the standard Loran-C format, with a group repetition interval (GRI) of 99,600 $\mu$s.

The radiated power of the LRTC transmitter can be calculated from the antenna base current and the radiation resistance, both of which can be measured. The Coast Guard uses a loop to sense the current in the antenna's ground return; this is the antenna base current. The method used to determine the radiation resistance involves a standard procedure of measuring field strength.

The simultaneous record of aircraft position uses triangulation techniques based on three existing or temporary radio beacons. This positioning system could be interfaced to the signal level recording system so that all data would be stored on the same medium. This is not necessary, however, and for simplicity will not be done. Instead, the positioning system will record on its own medium both the aircraft position and the time. So, if the clocks on both the signal level recording system and the positioning system are synchronized, the needed information is obtained.

The FAA will provide the aircraft position information as a function of time on magnetic tape. The instrumentation described in the remainder of this section will provide the received signal level as a function of time on magnetic tape.

During this year, the test plan (an informal report to the FAA) and data recording instrumentation have been developed. Planned for next year are the calibration flights and a determination of the calibration constant, which will be presented in a final report to the FAA. In the paragraphs that follow, the instrumentation and the calibration flight paths are briefly described.

The calibration instrumentation needed to record the received signal level and the time is based on a microprocessor. Other components include a spectrum analyzer, a digital magnetic tape deck, a clock, a computer terminal, a pre-amp, and an rf bandpass filter.

Within a day or two of the source calibration by the U.S. Coast Guard, the aircraft calibration flights must be made. These flights can be made at one altitude, 2 km/MSL. The flight paths over which received signal level data are to be collected are:

- outbound on a 90° T radial beginning directly over the source to beyond 100 km,
- inbound on a 135° T radial beginning beyond 100 km to directly over the source,
- one pass on a 20 km radius arc that crosses each radial,
- one pass on a 100 km radius arc that crosses each radial, and
- two passes on a 9 km orbit, one in each direction.

BEST DOCUMENT AVAILABLE

## CHAPTER 2. SYSTEMS ENGINEERING AND EVALUATION

The objective of this program subelement is to provide system oriented studies that are user-oriented where the user is a Federal mission agency. The studies are generally oriented toward defining system requirements, system design and evaluation, cost trade-off, development of performance criteria or standards, and user-acceptance criteria. The engineering work needed to carry out these studies takes the form of analyses, measurements, and performance evaluations with the results published in NTIA reports or, when applicable, in technical journals. Federal agencies use the results in planning, designing, specifying, procuring, leasing, and operating telecommunication systems.

Section 2.1 addresses those projects which are categorized as communication systems and services engineering, Section 2.2 presents those projects oriented toward terrestrial radio system performance and monitoring, and Section 2.3 deals with standards activities.

### SECTION 2.1 COMMUNICATION SYSTEMS AND SERVICES ENGINEERING

The following systems technology projects relate to established or planned communication services. The services are either procured or leased by mission agencies, and the engineering described here relates to the evaluation, performance criteria, measurement methods, or new technology required for efficient, cost-effective procuring, leasing, or establishing of these services. The projects described here are: Data Communications, Montana Telecommunications Architecture, NOAA-Weather Service Telecommunication Study, and Estimated Cost of a Submarine Fiber Cable System.

**Data Communications.** New applications for data communication services and the trend towards competition and deregulation in the telecommunications industry have created an urgent need for uniform methods of specifying and measuring the performance of data communication services as seen by the end user. Over the past 5 years, standards groups in the Federal government and industry have been working together to meet that need through the development of user-oriented, system-independent performance parameters and measurement methods. Results are being promulgated within the Federal government in the form of Federal Telecommunication/Federal Information Processing Standards, and in industry in the form of American National Standards. The Institute for Telecommunication Sciences has played a leading role in the development and promulgation of these standards.

Two related data communication performance standards have been developed. The first specifies a set of user-oriented performance parameters. That standard was initially approved, in 1979, as Interim Federal Standard 1033. It has since been applied successfully in a number of trial Federal procurements, and a similar industry standard has been developed by a task group of the American National Standards Institute. The latter standard is currently undergoing review and formal balloting within the American National Standards Institute (ANSI). It will ultimately replace Interim Federal Standard 1033 as a joint Federal Telecommunications/Federal Information Processing Standard.

Federal Standard 1033 and its ANSI counterpart are unique in providing a set of performance descriptors that can be applied to any digital communication service, irrespective of system design features such as topology and control protocol. This property of system independence makes the parameters useful as a "common language" for relating the performance needs of data communications users with the capabilities of offered systems and services. Serious deficiencies in communications management and increasing emphasis on competitive procurement demonstrate that such a capability is urgently needed in the Federal government. Similar needs exist in many non-Federal user organizations.

The second standard, proposed Federal Standard 1043, defines uniform measurement methods which enable users to obtain representative numerical values for the FS 1033 parameters. It was developed by the NTIA/ITS in 1980, and is currently being reviewed in government and industry as a first step towards approval as an Interim Federal Standard. It is anticipated that FS 1043 will follow an implementation path similar to that being followed by FS 1033; i.e., (1) trial application as an interim (optional) federal standard, (2) adaptation and approval by ANSI, and (3) Federal adoption of the ANSI version as a joint FTS/FIPS.

Federal Standard 1043 and its ANSI counterpart will promote innovation and fair competition in the data communications industry by providing users with a practical method of measuring delivered performance. Improved ability to measure performance will enable users to make more intelligent choices among service and equipment alternatives, and to define more economical, realistic communication requirements. The success of procompetitive/deregulatory Federal policy initiatives like the Second Computer Inquiry decision and Communications Act Rewrite will depend critically on such user abilities.

The Institute's FY 81 Data Communications project has focused on three major objectives:

1. Completing a set of experimental measurements demonstrating application of FS 1043 to the Advanced Research Projects Agency (ARPA) network.
2. Coordinating adaptation and approval of FS 1033 within ANSI, and FS 1043 within the Federal Telecommunications Standards Committee (FTSC).
3. Contributing to the work of international standards organizations developing user-oriented performance descriptors.

Figure 2-1 illustrates the functional design of the data extraction system which is being used in the ARPA network measurements. In this figure, the various participating entities are identified by vertical boundaries and time proceeds down. The source and destination users are ITS-developed application programs executing under real-time operating systems in two remote ARPA network host computers: one at NTIA/ITS in Boulder, CO, and one at the National Bureau of Standard's Institute for Computer Sciences and Technology in Gaithersburg, MD. The end-to-end communication system is represented as two "half-system" entities, one associated with each end user. Source and destination test operators are also shown. Normal program and control transfers are indicated by heavy lines, while exception processing, operator monitoring, and status messages are indicated by thin lines.

To generate a "batch" of measurement data, the source and destination user programs participate in a normal ARPA network file transfer, but also record the performance significance and time of occurrence of each user/system interface event. These interface events consist of system calls (Open, Close, Read, and Write) between the application programs and their associated operating systems. Measurement data are collected independently at each interface, and are then consolidated at one computer site for off-line analysis by a performance assessment program. Satellite clock receivers slaved to an NBS-generated time reference ensure millisecond accuracy in the determination of event times.

Recorded performance data sets are reduced to FS 1033 performance parameter values by an ITS-developed FORTRAN computer program. The performance assessment program and its input/output files are independent of measurement application, which allows them to be completely standardized. To enhance its transportability, the program is written in the 1966 ANSI standard FORTRAN.

The performance assessment software consists of a main driver program (ASSESS) and a set of subroutines that perform the various data processing procedures required to produce calculated parameter values. These program subroutines, along with the input/output files they reference, are shown in Figure 2-2. In this diagram, each subroutine at a given level is connected by a heavy line to a program element at the next higher level. The intended relation is that the higher level program element calls the subroutine. The left-to-right arrangement of subroutines at a given level indicates the order in which they are called by a particular program element. A thin line from an I/O file to a subroutine implies that the subroutine reads data from the file; a thin line in the opposite direction implies that the subroutine writes to the file.

A detailed description of each ASSESS subroutine is provided in the measurement standard. Briefly, subroutines ACCESS, TRANSF, DISENG, and SECOND calculate values for the access, user information transfer, disengagement, and secondary FS 1033 performance parameters, respectively. Subroutine ANCILL supports the former three programs in calculating values for the ancillary performance parameters. Subroutine DATCOR matches transmitted and received bits and identifies undelivered and extra bits to assist TRANSF in evaluating the user information transfer parameters. Subroutine SSTATE determines (a posteriori) the secondary (availability) state of the monitored service during a particular measurement period by comparing the measured values for certain "supported" user information transfer parameters with specified outage thresholds. Subroutine PROLOG and the subroutines under it prepare extracted performance data batches for processing. Subroutine EPILOG and the subroutines under it print and store the program outputs.

Results of the ARPA network measurements will be published in an NTIA report which will be available early in FY 82. It is expected that this demonstration measurements program will assist initial users of FS 1043 in characterizing the performance of other similar data communication networks.

There were several significant events during FY 81 with respect to the formal review and approval of these standards. In January of 1981, ANSI's Data Communications Subcommittee, X3S3, voted to distribute the ANSI version of FS 1033 (X3S35/125) to its full membership for formal balloting as an American National Standard. Task Group X3S35 is currently incorporating revisions suggested by the X3S3 reviewers. It is expected that a revised draft incorporating suggested revisions will be returned to X3S3 for further processing early in FY 82. In March of 1981 the National Bureau of Standards announced its intention to adopt the approved ANSI X3S35/125 standard as a Federal Information Processing Standard (FIPS). The Bureau's announcement solicited comments on the standard from Federal agencies and industry organizations, and it is expected that comments received will be incorporated in the standard along with those of the X3S3 reviewers. Earlier in March, the Federal Telecommunications Standards Committee voted to distribute proposed FS 1043 to industry and government reviewers as a first step towards its adoption as an Interim Federal Standard. A revised version of that standard will be submitted for formal FTSC balloting early in FY 82. As noted earlier, ANSI Task Group X3S35 is currently working to adapt FS 1043 for eventual proposal as an American National Standard.

The Institute contributed inputs to two international standard organizations during FY 81: the International Standards Organization (ISO) and the International Telephone and Telegraph Consultative Committee (CCITT). Both organizations are developing performance measures for describing quality of service in the Open Systems Interconnection (OSI) reference model, and CCITT Study Groups VII (Public Networks) and XVII (Data Transmission) are addressing a number of technical questions which deal specifically with performance specification and measurement.

Federal Standard 1033 is particularly appropriate for use in the OSI context because of its property of system independence. Since

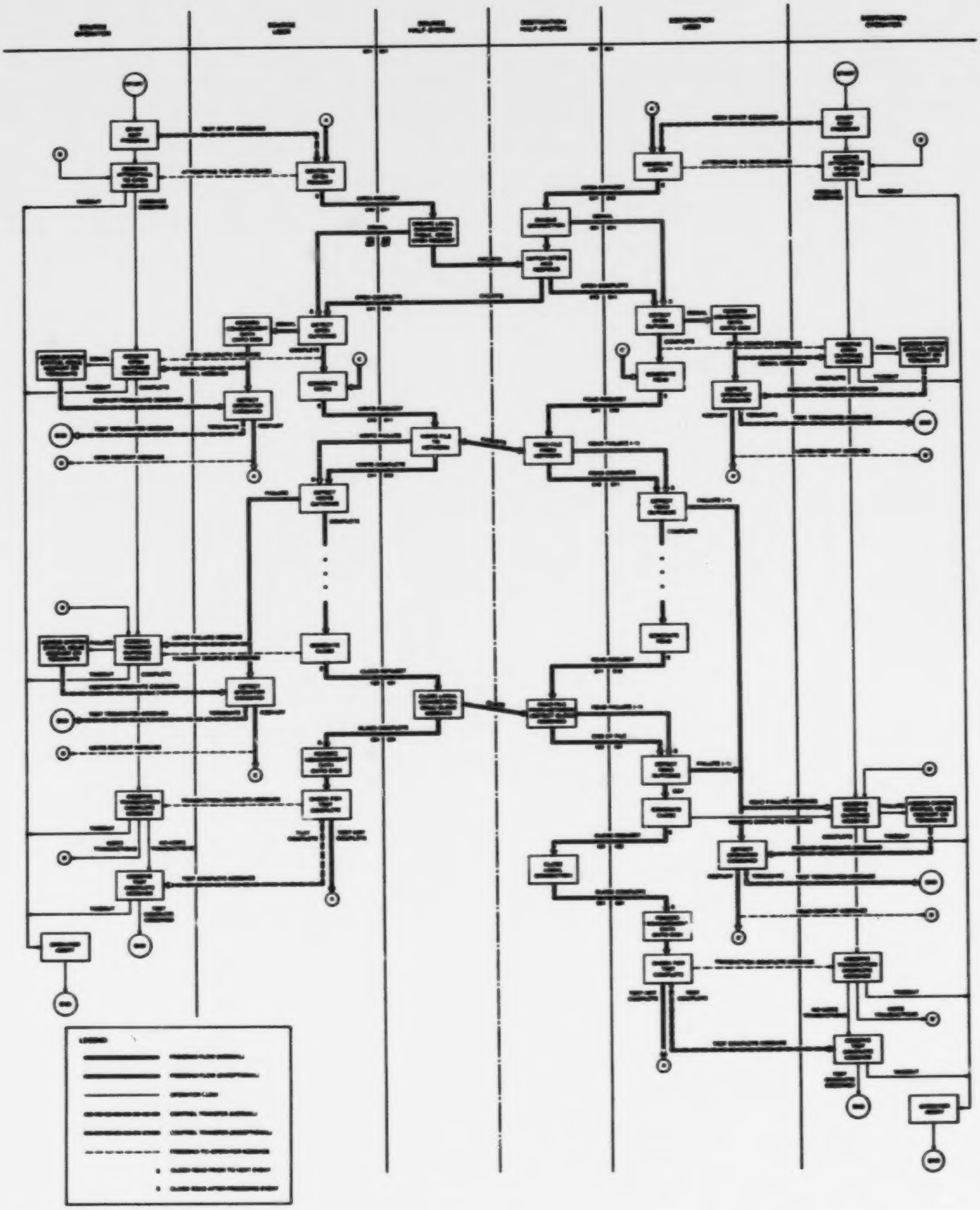


Figure 2-1. Data extraction subsystem functional design.

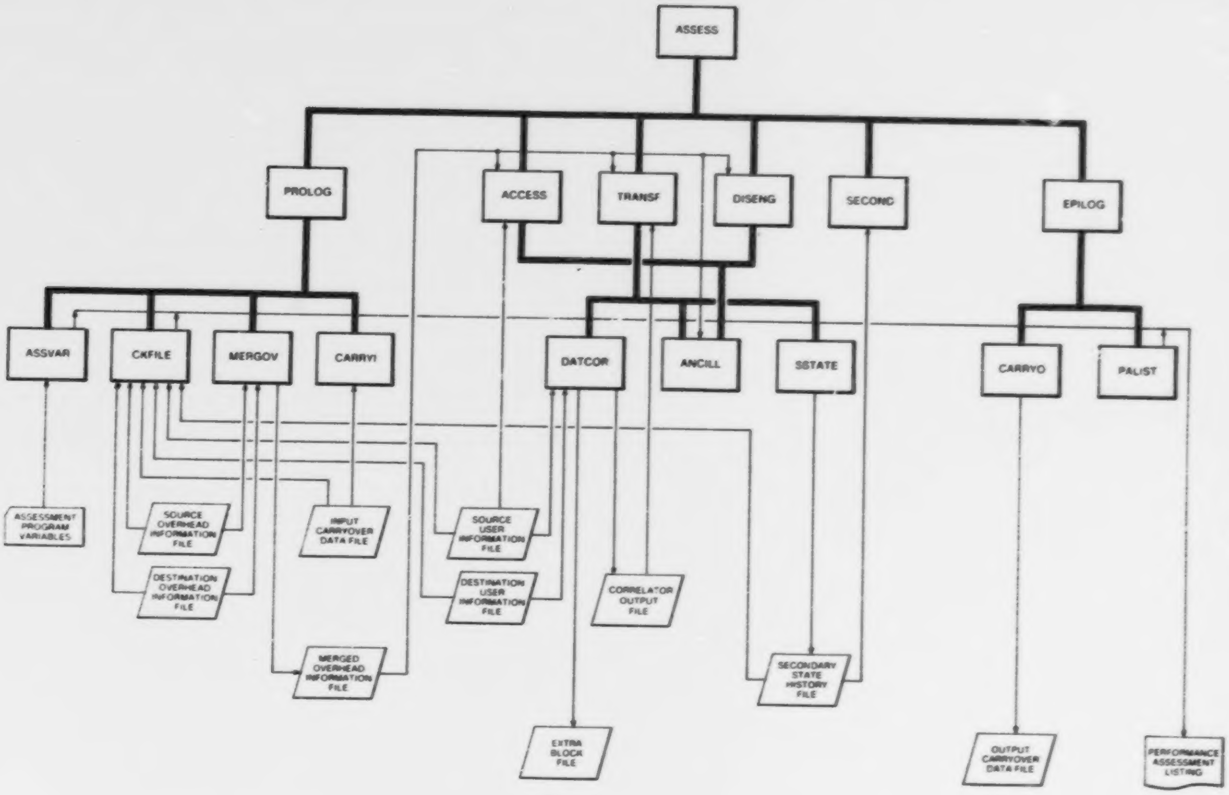

ASSESS
PROLOG
ACCESS
TRANSF
DISENG
SECONC
EPILOG
ASSVAR
CKFILE
MERGOV
CARRYI
DATCOR
ANCILL
SSTATE
CARRYO
PALIST
ASSESSMENT PROGRAM VARIABLES
SOURCE OVERHEAD INFORMATION FILE
DESTINATION OVERHEAD INFORMATION FILE
INPUT CARRYOVER DATA FILE
MERGED OVERHEAD INFORMATION FILE
SOURCE USER INFORMATION FILE
DESTINATION USER INFORMATION FILE
CORRELATOR OUTPUT FILE
EXTRA BLOCK FILE
SECONDARY STATE HISTORY FILE
OUTPUT CARRYOVER DATA FILE
PERFORMANCE ASSESSMENT LISTING

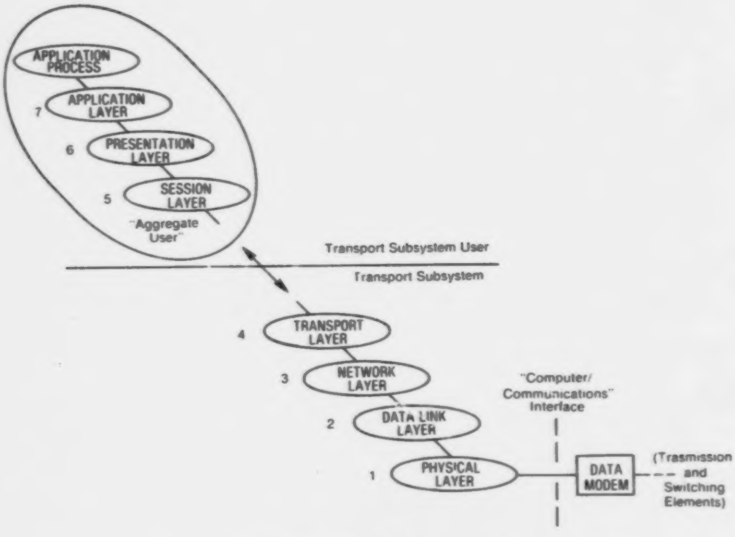
Figure 2-2. Performance assessment computer program and I/O files.

the standard can be applied at any pair of digital interfaces, it can be used to describe the services provided by any layer in the OSI hierarchy to the next higher layer, viewed as a user of those services. This broad applicability makes the standard useful in allocating end-to-end performance objectives to purchasable subsystems, and conversely, in determining the impact of subsystem performance on the end-to-end quality observed by the end user. Figure 2-3 illustrates one possible subsystem application. In this application, the subsystem interface is placed between the Session and Transport layers of a typical Open Systems Interconnection protocol hierarchy; the Application Process and the Application, Presentation, and Session layers are regarded as an "aggregated user" of the Transport Subsystem.

The Institute made two primary international standards contributions during FY 81. The first was submitted to ISO TC 97/SC 16/Working Group 6, which is responsible for defining the Transport and Session layers of the OSI reference model. That contribution recommended that a subset of the FS 1033 parameters be used in specifying the quality of service requested of the Transport layer during a particular data communication session. The NTIA/ITS approach was accepted by WG 6 and will be incorporated in a subsequent revision of the Transport Service Specification. In a companion contribution, NTIA/ITS defined a set of service performance classes, based on ranges of values for the FS 1033 parameters, which can be used to quantify available service performance options. Subsequent contributions will relate quality of service with the various Transport protocol options.

The second NTIA/ITS contribution was submitted to CCITT Study Group XVII, which develops recommendations to facilitate transmission of digital data over voice telephone networks. That contribution provided a simple procedure for relating statistical precision with the number of bits transmitted during a bit or block error rate test.

It is expected that the FY 82 Data Communications program will focus strongly on promoting effective competition in the provision of public data communication services. The Institute plans to procure or develop a microprocessor-based test set capable of extracting and recording the measurement data needed to calculate FS 1033 parameter values at a carrier/customer interface. This device will then be used in measuring the actual performance of a number of competing common carrier services. Extracted data will be reduced by the NTIA/ITS FORTRAN performance assessment program, and the results will be published in an NTIA



**Application Process and Application, Presentation, and Session Layers as an "Aggregate User" of the Transport Subsystem.**

Figure 2-3. Aggregate user concept.

report and one or more trade journal publications. This published data will assist users in comparing alternative service offerings on a performance basis.

The Institute also expects to play a more substantial role in the development of international standards during FY 82. Planned activities include chairmanship and support of the U.S. participation in CCITT Study Groups VII, XVII, and XVIII as well as additional contributions to ISO. These activities will enhance international market opportunities for the U.S. telecommunications industry through the development of appropriate technical standards, and will ensure that U.S. technical recommendations for international standards fairly represent the interests of competing U.S. industry organizations.

Montana Telecommunications Architecture. The primary goal of this project was to develop an integrated telecommunications concept and operational methodology for assessing the telecommunications needs of rural state and local government. A central part of this concept was to provide a mechanism for nontechnical administrators to develop intelligent short and long range integrated, telecommunication policies. In addition, the process encouraged shared technological resources with Federal agencies without imposing operational constraints and controls on the rural telecommunication providers and users. The integrated model incorporates methodologies designed to develop procedures by which

- the needs of all public telecommunications users and providers in a selected political jurisdiction (i.e., state, county, city, special district, . . .) may be routinely monitored, and
- developments in telecommunications technology with possible application to the needs of that jurisdiction (defined system) may be regularly assessed and evaluated.

The use of an integrated telecommunications model for the assessment of rural telecommunication needs and policy was intended to provide intelligent alternatives for rural economic development.

Initial attempts to advance the concept of integrated telecommunications planning met with some confusion due, in part, to the definition of "telecommunications." Each user group had a different perception of telecommunications based on their needs and identification with a particular aspect of the technology (i.e., telephony, data, land/mobile, video, . . .). Related professional associations and trade journals tended to reinforce those narrow definitions. To clarify the concept of telecommunications, from an integrated planning perspective, a telecommunication taxonomy was developed as illustrated in Figure 2-4. This integrative approach provided a more systematic method of analyzing the merits of integrating the various technologies at the operational and technical level. The ITS project team focused primarily on data and land/mobile radio methodologies.

ITS prepared "draft" data collection methodologies for the Montana telcommunications staff. These methodologies were designed to assess user operational needs and existing physical hardware inventory. This approach assumed that valid data was a prerequisite to intelligent decision-making. The methodologies were tested by a state subcontractor in selected areas and modified to best serve local needs.

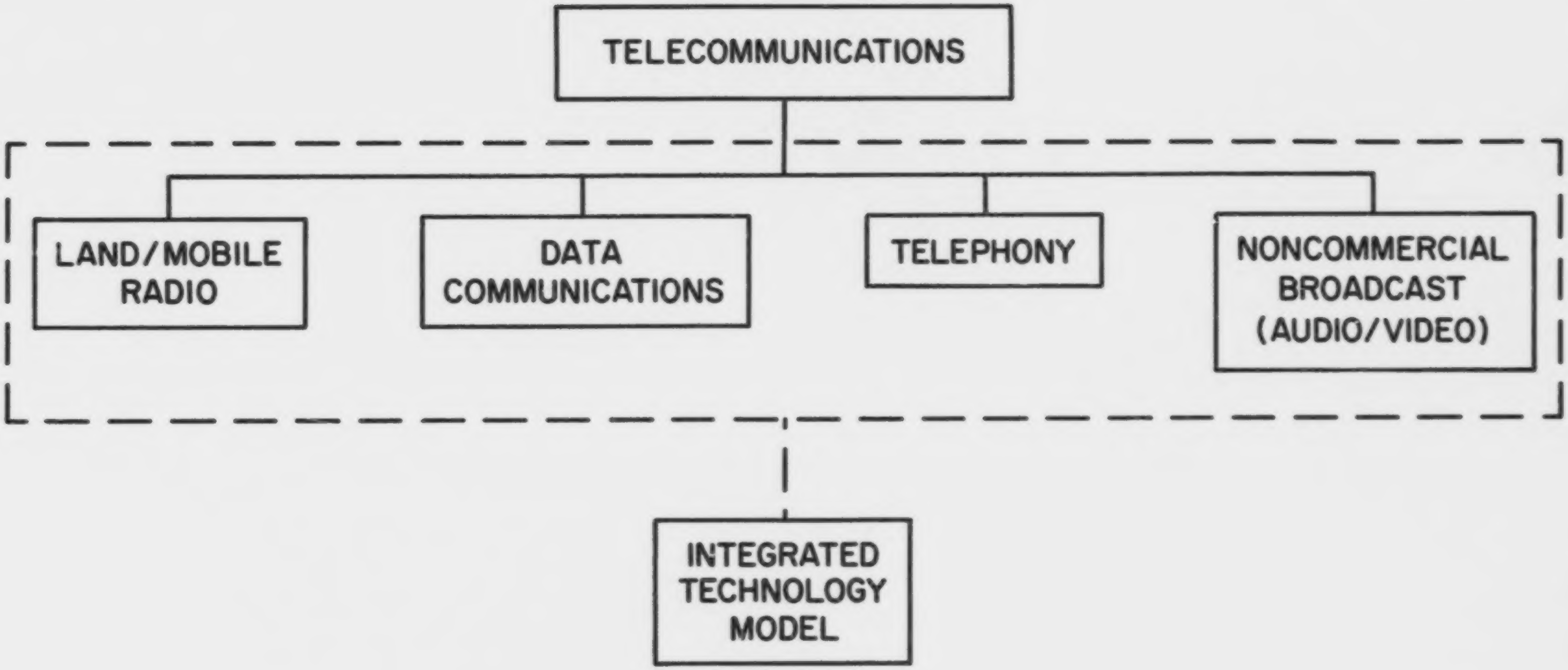

TELECOMMUNICATIONS
LAND/MOBILE RADIO
DATA COMMUNICATIONS
TELEPHONY
NONCOMMERCIAL BROADCAST (AUDIO/VIDEO)
INTEGRATED TECHNOLOGY MODEL

Figure 2-4. Telecommunications taxonomy.

The underlying process of the telecommunications needs assessment included data which would test the adequacy of the agency's existing overall telecommunications policy (i.e., degree of centralization/decentralization, lease/buy, common procurement, operational/technical standards, . . .). This in turn would surface issues and questions concerning the telecommunications goals and objectives of the agency. A flow chart of the land/mobile needs assessment process is shown in Figure 2-5.

Some short-term outcomes and completed tasks associated with the project are summarized below:

- Substantially higher telecommunications visability in the Governor's Office, State Legislature, and Public Service Commission (PSC).
    1. The Executive Branch is currently developing short and long-range telecommunication policies.
    2. The Legislative Branch has just authorized approximately $300,000 for detailed statewide telecommunications planning.
    3. The PSC has requested increased input from the state user agencies and completed initial telecommunications training for selected staff personnel.
- Initial State telecommunications planning funded by NTIA has developed an important overview of Montana State telecommunications needs, using an integrated approach.
- Telecommunications data collection methodologies have been tested and modified.
- Potential Federal and State telecommunications sharing projects were identified.

NOAA-Weather Service Telecommunication Study. The objective of the feasibility study was to assess the technical and economic feasibility of using communication satellites to meet part of NOAA telecommunications requirements.

NOAA provided ITS with information on their current telecommunications circuits and systems. ITS reviewed this information and identified the requirements which best fit with the use of communication satellites. Many of NOAA's telecommunications user requirements are low to medium bit rates. The relative significant number of low-speed users are widely dispersed geographically. The following list is a sample of dedicated terrestrial types of circuits in the U.S. that serve NOAA.

- Circuits that move weather information products between the National Meteorological Center (NMC) in Suitland, MD. and 50 Weather Service Forecast Offices (WSFO) in the U.S.
- Circuits that move weather data from weather sensor locations, Weather Service Offices (WSO), and WSFO's to the NMC.
- Weather facsimile circuits, such as NAFAX, and DIFAX.
- Circuits that move satellite weather imagery photos from Wallops Island/Suitland, MD. to Satellite Field Service Stations and then to WSFO's.
- Circuits (voice and data) that move command and control, raw spacecraft data, and other information between Suitland, MD. and the Command and Data Acquisition stations at Wallops, VA., and Gilmore Creek, AK.
- Circuits that move weather forecast products and warnings to the media, general public, special users, and others.

The ITS listed possible candidate alternative satellite concepts and selected three for detailed analysis and presentation in the study report. The selection of most likely system alternatives were based on a cost-effectiveness comparison between the selected alternative and the present telecommunications cost-effectiveness.

We considered present and future commercial common-carrier telecommunications satellite offerings and included in the study anticipated future NOAA telecommunication requirements.

The cost-effectiveness and technical feasibility of small ground stations that can be placed on NOAA premises was examined. Other communications concepts were also considered, such as a NOAA-owned satellite system and a cost analysis for this alternative was prepared. A final report is in the publication process.

Estimated Cost of a Submarine Fiber Cable System. Transatlantic communications capacity demands are currently growing at a rate of 20% to 25% per year. This rate of growth requires the doubling of transmission capacity each 3 1/2 years. Because of the high quality of submarine cable circuits and ease and convenience of International Direct Dialing, the continued rapid growth in demand will likely continue. The introduction of satellite service between the United States and Europe has had a delaying effect on cable demand, but the growth trend for cable continues. Table 2-1 shows the growth in capacity of transatlantic cable systems in 20 years as well as projected requirements for 1985 and 1990, based on a 22% annual growth rate. The trend as observed in Table 2-1 is clear: ever increasing cable size is required to accommodate ever increasing traffic demands. This is a basic characteristic of metallic coaxial transmission lines. Optical fiber waveguides offer a striking contrast in this regard. The size of the optical fiber has little influence on its capacity.

A study was carried out based on engineering judgment to project the per voice-channel/kilometer savings of a fiber system over the cost of the Transatlantic (TAT) Cable System 6 (TAT-6) for which cost figures were readily available. These figures (1980 World's

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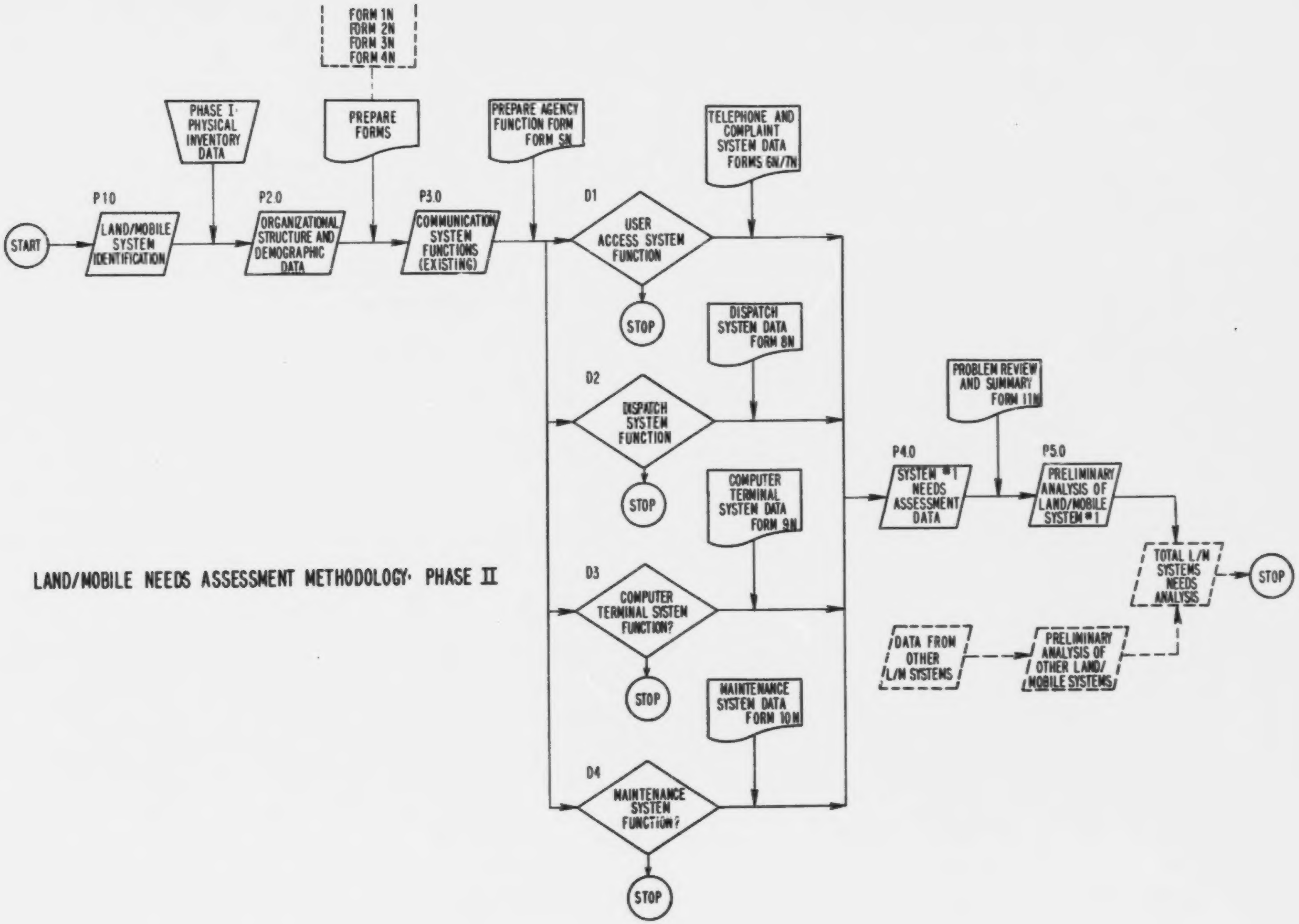
FORM 1N
FORM 2N
FORM 3N
FORM 4N
PHASE I· PHYSICAL INVENTORY DATA
PREPARE FORMS
PREPARE AGENCY FUNCTION FORM FORM 5N
TELEPHONE AND COMPLAINT SYSTEM DATA FORMS 6N/7N
START
P1.0
LAND/MOBILE SYSTEM IDENTIFICATION
P2.0
ORGANIZATIONAL STRUCTURE AND DEMOGRAPHIC DATA
P3.0
COMMUNICATION SYSTEM FUNCTIONS (EXISTING)
D1
USER ACCESS SYSTEM FUNCTION
STOP
DISPATCH SYSTEM DATA FORM 8N
D2
DISPATCH SYSTEM FUNCTION
STOP
PROBLEM REVIEW AND SUMMARY FORM 11N
P4.0
SYSTEM #1 NEEDS ASSESSMENT DATA
P5.0
PRELIMINARY ANALYSIS OF LAND/MOBILE SYSTEM #1
COMPUTER TERMINAL SYSTEM DATA FORM 9N
LAND/MOBILE NEEDS ASSESSMENT METHODOLOGY· PHASE II
D3
COMPUTER TERMINAL SYSTEM FUNCTION?
STOP
TOTAL L/M SYSTEMS NEEDS ANALYSIS
STOP
DATA FROM OTHER L/M SYSTEMS
PRELIMINARY ANALYSIS OF OTHER LAND/MOBILE SYSTEMS
MAINTENANCE SYSTEM DATA FORM 10N
D4
MAINTENANCE SYSTEM FUNCTION?
STOP

Figure 2-5. Flow chart of the land/mobile needs assessment process.

Submarine Telephone Cable Systems, NTIA Contractor Report 80-6 by R.J. O'Rorke, Jr.) were: total cost = $197M, distributed in the following way - cable 52.3%, installation 5.1%, and submerged electronics 39.6%. A fiber cable was assumed to contain 6 fibers, each of which would carry the traffic now carried by the TAT-6 system. A summary of the status and projected reliability of fiber components required for a system operating at 1300 nanometer wavelength was presented. A repeater spacing of 30 km was assumed (compared with the 9.5 km spacing of the TAT-6). Comparisons of a projected coaxial vs fiber optic cable for a 6300 km span (corresponding to TAT-6) may be obtained from Table 2-2.

To estimate the total fiber cable cost, the following equation was proposed:

$$C\ (\text{fiber}) = \alpha \cdot C_c + \beta \cdot C_e + \gamma \cdot C_t + \delta \cdot C;$$

where $\alpha$, $\beta$, $\gamma$, and $\delta$ are terms whose values were estimated on the basis of the tradeoffs developed in the report. The values of $C_c$, $C_e$, and $C_i$ were based on published costs of the TAT-6 system as shown in Table 2-3. $C_t$ is the terminal station and the terminal and power feed, $C_t$ = $6M.

The estimates of $\alpha$, $\beta$, $\gamma$, and $\delta$ are developed in the report. These are:

$$1.5 \leq \alpha \leq 2.0$$

$$1.5 \leq \beta \leq 2.0$$

$$\gamma = 1$$

$$0.4 \leq \delta \leq 0.7.$$

Therefore,

$$\$282\text{M} \leq C\ (\text{fiber}) \leq \$375\text{M}$$

and the corresponding normalized cost is:

$$\$3.55/\text{Ch}\cdot\text{km} \leq C\ (\text{fiber}) \leq \$4.70/\text{Ch}\cdot\text{km}$$

where a channel is understood to mean 64 kb/s voice channel or equivalent. The corresponding cost of the TAT-6 system was

$$C(\text{TAT-6}) = \$7.45/\text{Ch}\cdot\text{km}.$$

Thus, based on the estimates used in this study, cost savings range from 37% to 52%. The resultant fiber cable would contain 6 fibers providing 1 pair for two-way transmission, thus increasing the capacity of TAT-6 by threefold. The savings are accrued because of the threefold increase of capacity with only a slight increase in the cost of cable, electronics, laying, and powering of the system.

## SECTION 2.2 TERRESTRIAL RADIO SYSTEM PERFORMANCE AND MONITORING STUDIES

This activity is directed toward the design, evaluation, acceptance, operation, and upgrading of existing or proposed radio systems operated by the Federal Government. The projects generally result in recommendations for system design changes and/or system upgrading or for new monitoring and control methods. The projects described are: MARAD Assistance, Advanced DEB IV EFAS, U.S. Army Tactical Communications Systems - Digital Message Device Group Tests, Measurement of Performance of Mobile Radio in the Presence of Ignition noise, Automated Performance Predictions for Mixed Mode Links, Technical Support to the MEECN System, Multipath Induced Spectrum Distortion, PMTC Wideband System Performance, and Interoperability Parameter Hierarchy.

MARAD Assistance. The Institute continued to provide a range of technical services to the U.S. Maritime Administration (MARAD). For Fiscal Year 1981 the most significant efforts were in the following areas.

1. Spread Spectrum techniques. In FY 80 ITS performed an analytical study into the feasibility of an overlay spread-spectrum (SS) communication system in the VHF band (156-162 MHz) in the New Orleans, LA, area. The results of the study showed that simple overlay is not feasible principally because of interference with mobile reception between the base stations of the SS system and the existing FM systems (An Analysis of the Compatibility of Spread Spectrum and Narrowband FM Mobile Radio Systems in the 156 to 162 MHz Band, de Haas and Watterson, April 1981). Following a suggestion from MARAD, ITS is presently conducting a laboratory experiment to determine what can be gained by comb-filter notching of the spread-spectrum transmitted energy in such a way that the nulls would fall on the centers of the FM channels (see Figure 2-6). The advantages of such a scheme would be twofold:

   (a) the notches in the SS spectrum would reduce the interference to the FM system; and

   (b) corresponding notching at the SS receivers (particularly at the base station) could significantly reduce the FM to SS interference.

   In practice the actual gains will depend on the characteristics of present day FM equipments and the degree of complication and costs incurred in designing a notched SS system. The ITS study addresses specifically the SS to FM interference problem and the results of the study will be published in early FY 82.

2. The Institute provided the technical expertise in preparation for, and at, the Interim and Final Meetings of CCIR Study Group 8 in the areas of Direct Printing, Digital Selective Calling, and Automated VHF/UHF Telephony, all in the Maritime Mobile Service. This included U.S. representation in Interim Working Parties 8/5, Automated VHF/UHF Telephony, and 8/8, Operational Procedures for Digital Selective Calling. Both of these IWP's completed their work and submitted draft Recommendations to the Final Meeting of Study Group 8. The popularity of Direct Printing in accordance with CCIR Recommendation 476 is rapidly increasing. This technique is mostly used for telex connections with ships, but is also increasingly important for transmission of ship's operational data; e.g., payroll, requirements for provisions, etc. Due to the large increase in traffic,

Table 2-1. Transatlantic Cable Systems**

| Year | Total Voice Circuits (Cummulative) | Voice Circuit Added | System Nomenclature (added system) | Cable Size (cm) | Repeater Spacing (km) |
|---|---|---|---|---|---|
| 1956 | 36 | 36 | TAT-1 | 1.57 | 70.5 |
| 1959 | 72 | 36 | TAT-2 | 1.57 | 70.5 |
| 1963 | 212 | 140 | TAT-3 | 2.54 | 37.1 |
| 1965 | 352 | 140 | TAT-4 | 2.54 | 37.1 |
| 1970 | 1172 | 820 | TAT-5 | 3.81[1] | 18.6 |
| 1976 | 5372 | 4200 | TAT-6 | 4.32[1] | 9.5 |
| 1985 | 32165*** | 26790*** | | | |
| 1990 | 86930*** | 81558*** | | | |

** Source: 1980 World's Submarine Telephone Cable Systems, NTIA Contractor Report 80-6 by R.J. O'Rorke, Jr.
O'Rorke (1980).

*** Estimated, based on 22% annual growth.

[1] These reported values (from O'Rorke, 1980) are the inside diameter of the outer copper conductor. Outside cable diameter is 4.45 cm for TAT-5 and 5.26 cm for TAT-6. The outside diameter is the dimension of interest in later calculations.

Table 2-2. Comparison of Fiber Cable and SG (Western Electric Size Designation) Coaxial Cable

| Parameter | Value for fiber cable | Value for coaxial cable | Ratio Coax:Fiber | Comments |
|---|---|---|---|---|
| Cable Weight | 5500 lbs/km | 6900 lbs/km | 1.25:1 | Fiber weight is estimated and based on the elimination of outer coaxial conductor only. |
| Cable size | 2.1 cm | 5.26 cm | 2.50:1 | Variations on fiber cable size are effected as refinements in system plan evolve. Values used here are based on "Single-mode Digital Transmission Technology," by T. Kimura, Proc. IEEE, 68, 1263-1268 (1980). |
| Cable Volume (6300 km) | 2200 $m^3$ | 13700 $m^3$ | 6.27:1 | |
| Repeater Spacing | 30 km | 9.5 km | 3.16:1 | Fiber repeater spacing assumes that loss is the limiter. |

*Values for the SG cable are taken from O'Rorke, 1980 and "Installation and Maintenance of the Undersea System," BSTJ 57, 2523-2546, (1978) by J.E. H. Cosier, et al.

Table 2-3. TAT-6 Costs

| Component | Cost ($ Millions) |
|---|---|
| Cable ($C_c$) | $ 103 |
| Submerged electronics ($C_e$) | 78 |
| Terminal & power feed ($C_t$) | 5 |
| Terminal Stations ($C_t$) | 1 |
| Installation ($C_i$) | 10 |
| TOTAL | $ 197 million |

Normalized Total Cost: $7.45/ch·km*.

*TAT-6 is 6300 km, 4200 voice channels.

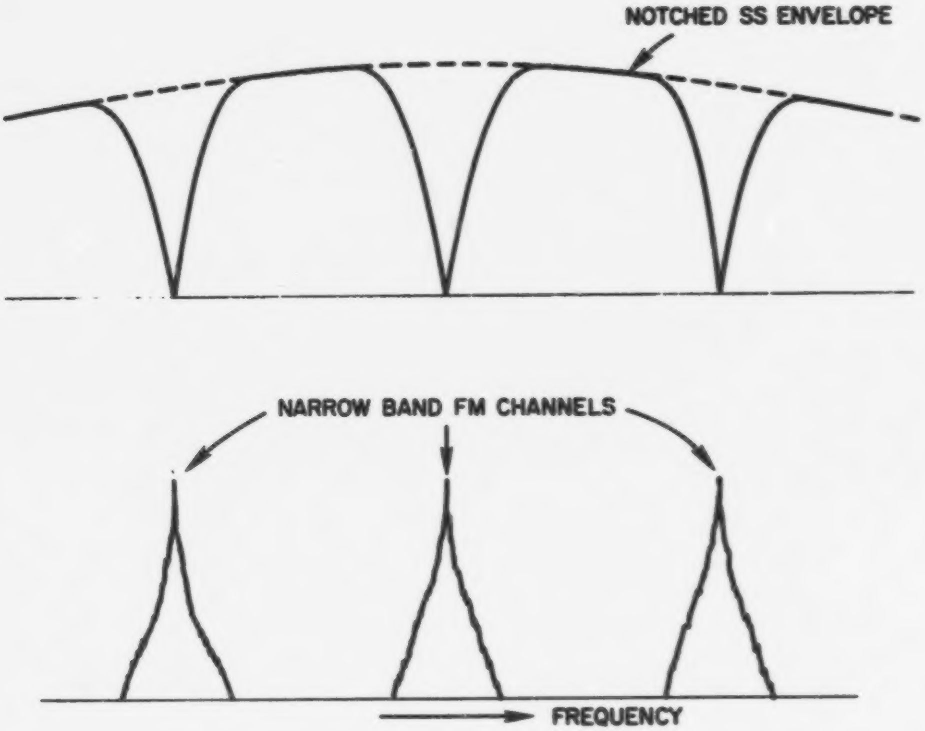

Figure 2-6. Notched spread spectrum overlay.

interference has also become an increasing problem and the need has arisen for automatic identification of the ends of the radio circuit (as opposed to the end users) when setting up a connection. The Institute has provided the technical expertise in this area, including preparation of U.S. proposals to the Final Meeting of Study Group 8.

Radio Technical Commission for Marine Services (RTCM) Sub-Committee 74 was established to coordinate U.S. efforts on Digital Selective Calling. An operational at sea test, planned by SC-74, unfortunately was not very successful because of unexpected equipment problems both on ship and at participating coast stations. New tests, if funding can be found, will place much increased emphasis on the preparatory efforts and pre-test check outs.

Funding for the ITS efforts in the CCIR preparatory work and meeting participation was partially supplied from NTIA in-house funds.

Advanced DEB IV EFAS. The objective of this program is to design and develop an intelligent second generation transmission monitoring and control system. The system is to be used to monitor several digital microwave terminals and relays within a network. The monitoring system is intended to provide the system operators with sufficient alarm and parameter data to isolate degraded conditions and faults at remote locations. Interactive displays are the core of the system that will assure efficient communication system operation.

Progress to date has included the definition of the system approach and objectives. These are now in distribution among the user agencies in anticipation of a users forum to be established late in the fall of 1981 to refine system requirements. Several management and technical working group meetings have been called to provide the necessary directions for this program.

This entire system is a second evolutionary step for a system first developed at ITS as the Enhanced Fault Alarm system.

U.S.Army Tactical Communication Systems - Digital Message Device Group Tests. The purpose of this project is to (a) determine specific performance capabilities of a Digital Message Device Group (DMDG) frequency-shift-keyed (FSK), burst-communications, HF modem using the ITS Ionospheric Channel Simulator, and (b) to prepare a final report on the results of the channel simulator measurements.

A first set of measurements was completed on the KY-879/P modem and a report written. The purpose of the laboratory experiments was to determine the error-probability performance of the modem with respect to various types of signal distortion imposed by HF channels and the modems themselves. The results of the experiments are to be used to determine if the modem meets five specified performance requirements.

A second set of measurements is being made as a result of several design modifications made to the KY-879/P after the completion of the first set of channel-simulator experiments.

Each channel-simulator experiment on the KY-879/P modem consisted of a set of error-probability experiments. Each measurement required the repeated transmission of the same message. To allow any keyed and stored message to be automatically repeated, and transmitted, a PROM (programmable read-only memory) in the KY-879/P transmitter was modified by the modem's manufacturer especially for the ITS channel-simulator experiments. Quiescent time between transmitted messages could also be entered from the keyboard.

A computer program was prepared, tested, and then used in the experiments to automatically *obtain, process, and display the* desired data during the course of each measurement. During each measurement, the computer counted the number of Tx-On (transmitter on) pulses to obtain the number of messages transmitted, $M_t$, and it counted the number of Rx-On (receiver on) pulses to obtain the number of messages received, $M_r$. The computer used the beginning of each Rx-On pulse to look for and read the ASCII characters delivered by the receiver for the specified number of blocks. When a message was delivered and read, it was processed by the computer, which compared it with the stored correct message, character by character, and added suitable counts to stored values for the measurement. These values were: $M_p$, number of messages processed; $C_p$, number of characters processed; $C_e$, number of processed characters in error (one or more bits in error); $B_p$, number of processed blocks in error (one or more characters in error); and b(n), number of blocks with n character errors, for n = 0, 1, 2, ..., 13.

For each transmitted message, the computer used six of 21 current stored counts to compute updated estimates of three error probabilities: probability of a missed message,

$$\hat{P}_m = \frac{M_t - M_r}{M_t}$$

probability of character error, given that a message is received,

$$\hat{P}'_C = \frac{C_e}{C_p} \quad ;$$

probability of a block error, given that a message is received,

$$\hat{P}'_B = \frac{B_e}{B_p}$$

A total of nine channel-simulator experiments were performed on the KY-879/P modem. The experiments are divided into two major types: nonfading experiments using a channel with a single specular (nonfading) path, and fading experiments using a channel with one or two Gaussian-scatter (Rayleigh-fading) paths. While the fading experiments all used realistic simulations of HF ionospheric (sky-wave) channels, the nonfading experiments did not because HF ionospheric channels always exhibit Rayleigh fading. The nonfading experiments were very desirable, however, because they provide useful performance capabilities information. The channel-simulator experiments performed were as follows:

A. Nonfading

1. Demodulator additive and nonlinear distortions.
2. Demodulator Doppler distortion.
3. Channel thermal-noise distortion.

B. Fading

1. Channel fading distortion.
2. Demodulator Doppler distortion with fading.
3. Channel thermal-noise distortion with fading.
4. Channel differential-delay distortion with fading.

Measurement of Performance of Mobile Radio in the Presence of Ignition Noise. A test program, sponsored by the Motor Vehicle Manufacturers Association, was undertaken at the General Motors proving ground for the purpose of determining the effects of vehicle ignition noise on land-mobile voice communication systems. Ten different test configurations involving up to 12 vehicles were used. The test results include both subjective scoring (listener panel) of phonetically balanced word groups and objective scoring. A report including these results has been sent to the sponsor for review.

Automated Performance Predictions for Mixed Mode Links. In the operation of near-line-of-sight and beyond-the-horizon microwave links, performance may be determined by more then one mode of radio wave propagation. This may come about as the result of a complete change from one mode to another or from two or more modes existing simultaneously. The objective of this project is to use the distribution of the apparent earth's radii for a given area as the data base for the algorithms used to calculate link performance. The algorithms and data base will be used in a second phase of work to prepare computer programs and document them for conveniently using these algorithms. This project is sponsored by the U.S. Army Communications Electronics Engineering Installation Agency.

Technical Support to the MEECN System. This is a continuing program which supports the MEECN (Minimum Essential Emergency Communications Network) System Engineer, at the Defense Communications Agency (DCA). A draft test plan has been completed and submitted to DCA for approval. Testing, which will be conducted at NOSC, San Diego, CA, will be directed by ITS and will address the interoperability (compatibility) issues of the updated and modified U.S. Air Force and Navy components of the MEECN System under various detrimental channel conditions, both natural and manmade.

Testing has been delayed by several months because of equipment shortfall. In the meantime, several new issues have been added by DCA, including synchronization testing of the latest operational program for the current Navy equipment presently in the field.

Multipath Induced Spectrum Distortion. Multipath fading in LOS links is known to cause short term outages when the signals from both the primary and diversity radios fade below the bit-error-rate threshold during flat fading. In addition, outages have been observed which occur at relatively high signal levels. These outages are often attributable to in-band (selective) fading.

To obtain statistics on selective fading and relate them to flat-fading information, the Defense Communication Engineering Center provided ITS with funds to investigate this problem. The project consisted of a 2-month test by ITS to assist in determining the effect of selective multipath fading on digital line-of-sight microwave links. Data were collected within the Digital European Backbone Stage I (DEB I) on three LOS links on which ITS had instrumentation installed for another test program. Data collected on this selective-fading project were analyzed at the ITS laboratory. A number of interesting results were observed from the data analysis. Large values of distortion, greater than 1 dB/MHz, were observed during multipath fading events due to nulls in the path frequency response. Diversity reception looks very promising for counteracting these large magnitude distortion effects. Multipath received-signal-level statistics can be used to predict the frequency and severity of in-band-fading distortion on line-of-sight paths. Frequency-selective fading develops and subsides at low rates, often over a period longer than one minute. These results are needed for improving performance and design criteria for digital LOS links. An NTIA report on this work will be published in the near future.

Digital Microwave Radio Evaluation. In 1978, the ITS conducted measurements over a microwave link at the Pacific Missile Test Center (U.S. Navy) at Point Mugu, CA. The objectives of the program were to characterize the multipath propagation due to atmospheric layering, and to assess its effect on a proposed digital transmission system. The meteorological structure off the coast of southern California is usually dominated by a marine layer of air that persists during the summer and fall months of the year. Strong temperature inversions develop, which in turn create superrefractive conditions for the radio signals. The refractive layers may be surface based and extend up to a few thousand feet, or they may develop as elevated layers at varying heights above the surface. Both conditions give rise to multipath. The results of the above measurements and the recommendations for implementing a digital microwave system over the test link were presented in NTIA Report 79-24, "Investigation of Digital Microwave Communications in a Strong Meteorological Ducting Environment," by R.W. Hubbard.

The particular link at PMTC is over a 65 mile (104.6 km) path from Laguna Peak (LP) near the Naval Base, to San Nicholas Island (SNI) in the Channel Islands offshore. The elevation of LP is approximately 1400 ft (426.7 m) above msl. The SNI terminal is approximately 900 ft (274.3 m) above msl. The entire path is over water with the exception of the steep terrain at each end that drops toward the ocean. The geometry of the link and the 10 ft (3 m) parabolic antennas used at each terminal, minimize the potential of surface reflection. Thus, the fact that the link is over water is insignificant to the propagation. The major concern is the meteorological conditions. Because the conditions do persist, and are well documented with radiosonde measurements, the LP-SNI link makes an ideal test bed for studying and evaluating atmospheric multipath.

Subsequent to the experiments conducted in 1978, the PMTC has purchased and installed a digital microwave radio for use over the LP-SNI link. The system is presently being used for experimentation only, and has been instrumented by PMTC and ITS for a comprehensive experiment to measure and correlate propagation conditions and digital system performance. The digital radio is a 44.7 Mb/s system, operating in an 8-PSK modulation mode. The test used for performance monitoring is a DS-test signal generated from a PN binary sequence. Two monitor instruments are used. The first is a synchronous error-second instrument, which is followed by a burst-error analyzer. The bit-error data from the error-second instrument is fed directly to the second instrument, which provides a distribution of the error data within a defined burst period. These data are being accumulated in a digital data acquisition system, for later processing and analysis at PMTC. At this writing, the performance data have not been processed to any extent.

The equipment configuration for the LP-SNI link is outlined below:

1. The monitored transmission is in simplex mode, with the transmitter located at SNI and the receiver located at LP.
2. A single transmitting antenna is used at SNI for all analog and digital signals.
3. The PN Probe is duplexed into the PMTC operating system at both terminals, so that the impulse response measurements are performed over precisely the same transmission channels as the operating systems.
4. Space diversity with approximately 125 ft (38 m) vertical spacing is provided at the LP receiving terminal.
5. Transmission signals and frequencies are as follows:

   Analog FDM System : 7170 and 7470 MHz

   Digital System : 7350 MHz

   PN Probe System : 8600 MHz.
6. Two 4-ft (1.2 m) parabolic antennas are mounted at the LP terminal for angle diversity measurements. These antennas are at a height of approximately 40 ft (12.2 m), just above the 10 ft (3 m) antenna used as the lower diversity antenna.

Multipath conditions in the more recent measurements are essentially the same as those observed in 1978. A summary of the multipath data for the PMTC link is presented in Table 2-4. It can be noted that the maximum delay times for the 1980 data are considerably longer than any registered in 1978. One explanation for this result is that the ducting layers in the atmosphere during 1980 were generally higher than those observed in 1978. Since the atmospheric multipath is due to refracted energy from the elevated layers, the delay spread would be greater. It has not been possible to analyze a great deal of the more recent data, but the examples presented in Table 2-4 are quite typical of the measurements to date.

The important aspect of atmospheric multipath is, of course, its dynamic effect on system performance. To illustrate the effect, we present an example of data that corresponds to a measured error event as received on the PMTC digital radio. This particular radio uses a digital scrambler (internal) with the purpose of creating a signal spectrum that maintains a uniform power density regardless of the actual data stream. In addition, the IF amplifiers in the receivers are designed for uniform gain across the signal spectra. These two design features produce a stable, flat spectrum for the signal as illustrated in Figure 2-7, where there is no transmission degradation. Since the normal spectrum is quite flat across the band, it is ideal for evaluating the effects of frequency selective fading; both the "tilt" and "notch." A series of spectra are shown in Figure 2-8, measured at the times indicated. Each sample corresponds to an error event observed on the digital radio. For this particular sequence, the receiver was taken out of its diversity-switching mode, and latched to receive data on the upper-antenna channel only. The adaptive equalizer on the channel was active, however, so that its full compensation for both spectral tilt and center nulls would be realized. The impulse response associated with each spectral plot is shown in Figure 2-8. The multipath component in these functions is nearly the same magnitude as the more direct component, and fairly consistent. The delayed component can be readily seen in the response of part (b) in Figure 2-8, as two distinct peaks are visible, with a slight notch between them. The responses of part (a) and (c) are broadened by the multipath, and the strong delayed component is confirmed only by the broadening of the response compared to a 13.3 ns width of a clear channel response. The delay time of the component is approximately 6 ns, as seen in the response of (b).

The tilt on the spectral functions in (a) and (c) are on the order of 10 dB or less across the 20 MHz bandwidth (0.5 dB/MHz). The distortion appears slight but it is of the same order of magnitude that has been found to produce unacceptable level of performance due to error rate. Each of the functions in Figure 2-8 were observed simultaneously with a burst error event in the PMTC performance data. The responses shown in part (b) were part of a continuing distortion that began a few seconds earlier with the responses shown in part (a) of the figure. The system returned to error-free performance following the notch that impinged on the spectrum in (b) until the response seen in (c) was observed approximately 2 minutes later. This activity continued with similar results for several minutes until a strong notch was seen to move through the spectrum at 1920:59. The responses at this time are shown in Figure 2-9.

Burst-error performance characterized the entire period when the above multipath activity was dominant. On occasion, a burst of errors was sufficient in length to cause a complete loss of synchronization in the received bit stream, which compounds the performance problems. It should be kept in mind that these measurements were made without benefit of space diversity, but with full compensation of the adaptive equalizer in the receiver. Channel A, the lower antenna path, was subject to the same type of distortion during the period, but less frequently.

All of the data are being processed at Point Mugu Test Center to establish the correlation properties between the multipath environment and the system performance. A NTIA report is expected to be published in FY 82.

Table 2-4. Multipath Delay Spread

| Date | Time | | Lower Antenna Delay (ns) | | Upper Antenna Delay | |
|---|---|---|---|---|---|---|
| | | | Max | High Prob. | Max | High Prob. |
| 22 Aug. 78 | 1550 | 1735 | 14 | 2 | 8 | 2 |
| *22 Aug. 78 | 1740 | 1750 | 5 | - | ** | |
| *24 Aug. 78 | 0907 | 0930 | 12.5 | 0 | 2 | ** |
| *24 Aug. 78 | 1515 | 1645 | 1 | 0 | ** | ** |
| *25 Aug. 78 | 0900 | 0950 | 2 | ** | ** | ** |
| 31 Aug. 78 | 1112 | 1200 | 8.7 | 5 | 8.7 | 5 |
| 1 Sept. 78 | 1005 | 1055 | 12 | 8 | 12 | 10 |
| *1 Sept. 78 | 1155 | 1435 | 8 | 6 | 8 | 6 |
| *5 Sept. 78 | 1705 | 2300 | 7 | 5 | ** | 1.2 |
| 6 Sept. 78 | 1635 | 1910 | 8 | 5 | 8 | 4 |
| 6 Sept. 78 | 1957 | 2155 | 9 | 5 | 10 | 7 |
| 8 Sept. 78 | 0030 | 0207 | 12 | 6 | 11 | 1 |
| 8 Sept. 78 | 0445 | 0649 | 14 | 7-13 | 11 | 6 |
| 10 Sept. 78 | 0550 | 0740 | 5 | 3.5 | 8 | 4-6 |
| 11 Sept. 78 | 0947 | 1100 | 5 | 3.5 | 9 | 4 |
| 13 Sept. 78 | 1630 | 1654 | 9 | 2-5 | 11 | 5 |
| *14 Sept. 78 | 1100 | 1200 | 2 | 0 | 2 | 0 |
| 12 Sept. 80 | 1800 | 1900 | 11 | 7 | 40 | 20 |
| 18 Sept. 80 | 2240 | 2400 | 19 | 8 | 40 | 9-14 |

Antenna Spacing ≈125'

** = Less than clear channel response, indicating phase interference fading.

* Measurement @ 50 MHz PN Clock Rate.

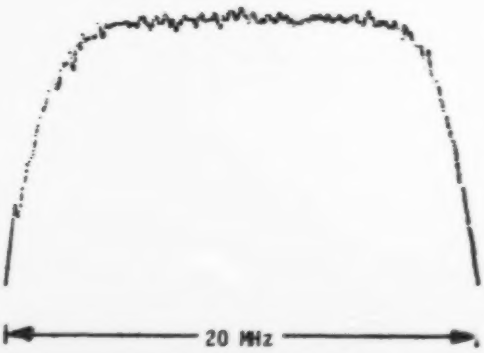

Figure 2-7. An example of the spectrum of the received digital signal over the PMTC link with no multipath degradation.

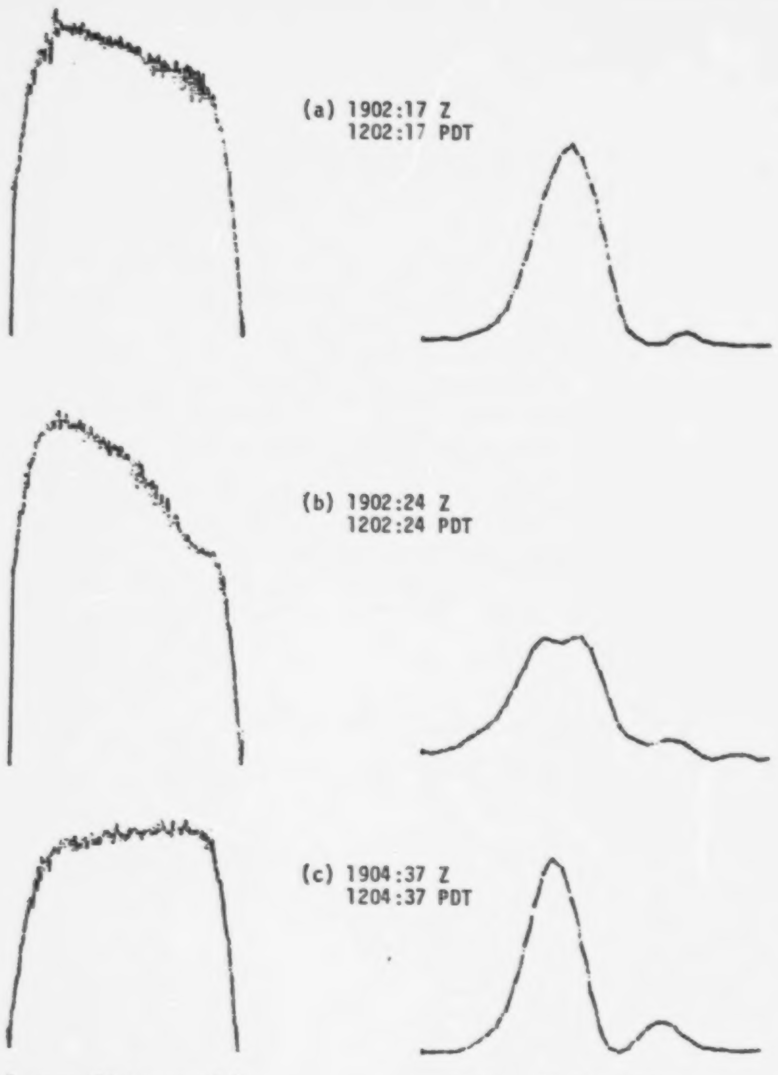

Figure 2-8. A sequence of signal spectra and power impulse functions measured over the PMTC link with atmospheric multipath. Each response corresponds to a time when burst-error data were observed in the digital radio performance.

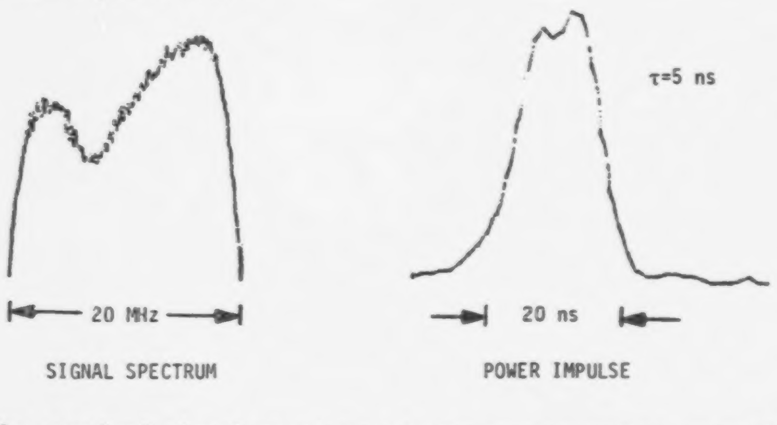

Figure 2-9. The received signal spectrum and the corresponding power impulse response in the PMTC channel with a strong multipath component.

Interoperability Parameter Hierarchy. Military interoperability issues bridge all tactical and strategic command levels. The issues include interface with host country commercial and national networks. This project was an initial phase of a multiphase effort addressing gateway interoperability evaluation. The work concentrated on the development of a methodology to evaluate interoperability. Several primary issues were identified and the hierarchy of elements and parameters required to characterize each issue was specified. The interoperability issues were organized as functional-parameter trees that represent status snapshots in time and space. A life cycle management system was proposed. Recommendations for further data collection, organization of interoperability evaluation methods into a facility, and the integration of this facility into the life cycle management system were made.

## SECTION 2.3 STANDARDS

The specific projects described here represent development of, contributions to, or specific applications of Federal, International, and industry standards. The projects are: Videotex Standards and Recommendations, Automated Digital System Engineering Models, and Automated Digital System Engineering Models.

Videotex Standards and Recommendations. NTIA/ITS, during the past two years, has addressed a large number of technical issues regarding the interfacing requirements and standards for decoders and systems designed to work with TV receivers as display terminals. A program within ITS was established to examine and comment upon the evolving National and International Standards and technical issues relating to Videotex services and the interworking of Videotex with other services. To keep current on standards and recommendations and to contribute to the U.S. standards activities, ITS has participated in a number of the Electronics Industries Association (EIA), and U.S. CCITT Study Group meetings and also technical symposia dealing with these technologies. TV manufacturers, broadcasters, and information provider industries are all seeking entry into what may become an important and profitable service industry within the next couple of years. Trade magazine articles have indicated that 1981 development costs for teletext/videotext may exceed $100,000,000 (*Business Week*, June 29, 1981, p.76).

FY 81 activities in an ITS project, "TV-Receiver-Interface Standards for Information Services" was focused on (1) support of the standards activities of the EIA and CCITT/CCIR organizations in their endeavors to develop and promulgate standards and recommendations for Videotex and (2) preparation of a technical data base for NTIA in support of Comments and Replies by NTIA to the FCC in connection with NOI's, Rulemakings, Petitions, etc.

In the International CCITT Study Group VIII, the matter of interactive Videotex has been a subject of debate for the past two years and has led to a number of recommendations at the September 1980 Plenary (Plenary Document No. 88E). Recommendations have been made to participating Administrations relating to transponder interoperability and terminal compatibility. These recommendations are mindful of the multiplicity of Videotex systems in operation or in field trials, in Europe and other parts of the world. The recommendations consider the following:

-- Interactive Videotex as an international service in accordance with CCITT recommendations.

-- Interworking of Videotex with Teletext and other text communication services such as Teletex, Telex, etc.

-- Early implementation of Videotex as a public service.

-- Common language, codes, and protocols to be accepted where possible to allow for minimum translation or character reworking.

It is agreed within the CCITT Working Groups that the various Administration (and not the CCITT or CCIR) should determine the (technical and special feature) basis for the country's own Videotex Systems, but at the same time, to move toward methods for suitable interconnectability to allow for interaction with Videotex Systems in other countries.

In the U.S., focus within the EIA and the TV/Cable industries appears to be directed toward broadcast videotex (Teletext) and much of the ITS effort has been toward participation in the teletext standards areas.

A summary of teletext standards status in the U.S. is listed below.

-- The EIA Teletext Subcommittee has actively sought to obtain concensus on a large number of technical standards needed to get this technology into the marketplace.

-- Page format and upper and lower bounds have been identified to enable the establishment of an acceptable page character matrix and display matrix for text and graphic presentation on a TV screen.

-- Bit rates for U.S. NTSC teletext operations, although not yet established, will either be at the 5.73 or the 4.58 Mb/s rates. The highest rate of 6.2 Mb/s appears unsuitable for U.S. standards due to the lower bandwidth and number of scan lines for the North American TV, the NTSC-M standard.

-- Forward error correction, probably using a form of Hamming Code insertion, appears to offer good low error rate teletext reception except under very low signal levels or extreme noise environments. Bit rates of 4.53 Mb/s would extend the acceptable viewing distances from transmitter to receiver and would probably give better teletext reception in noisy environments.

-- The asychronous (variable format)

approach of Telidon/Antiope appears to be the leading contender for a common North American Teletext System Standard. [This does raise the question of software compatibility for the United Kingdom generated software as well as that for most European teletext systems which operate with the same format at the British.]

A collection of papers, reports, and meeting notes have been assembled into Notebooks in ITS covering the topics of videotex and teletext standards. The notebooks also include entries from various national and international standards committees. A "Table of Contents" listing the reference material contained in the notebooks has been prepared and is available on request from ITS.

A more extensive Technical Memorandum is in process covering the Videotex Standards and recommendations.

Automated Digital System Engineering Models. The objective of this project is to expand the utility of a desk-top, computer-based set of programs previously developed by ITS for the U.S. Army Communications Electronic Engineering Installation Agency (USA CEEIA), Ft. Huachuca, AZ. Suitable additional programs and program modifications were prepared and tested with required documentation.

The program modifications are designed to reflect changes in LOS system standards based on work done at the Defense Communications Engineering Center at Reston, VA. The project is sponsored by USA CEEIA.

Guided Wave Communications. The work in this project was designed to 1) keep abreast of technological developments, 2) revise and update the Optical Communications Glossary, and 3) to provide a status report on the progress of fiber optic communications. These project objectives were met through attendance at technical meetings, the chairing and follow-up of a U.S. and Canadian glossary committee of experts, and the preparation of a report based on published information and personal contacts.

The first version of the Optical Waveguide Communications Glossary is in the reivew process to be accepted by both IEEE and EIA standards committees. A revised and expanded version will be substituted for the first edition when it is published (prior to the end of FY 81). The revised version is also expected to be submitted by IEEE to the IEC as a U.S. contribution to that international standards effort.

A revised and expanded version of an earlier report, "A User's Manual for Optical Waveguide Communications," by R.L. Gallawa, has been developed and will be published.

## CHAPTER 3. EM WAVE TRANSMISSION

The ground, the atmosphere, and the ionosphere degrade radio waves in varying degrees, depending on circumstances. It is the purpose of the EM Wave Transmission Program to study these effects and provide models to the system designer that will aid him in providing more cost effective and spectrum efficient designs. The phenomena which cause these detrimental effects on radio and optical systems are, in general, frequency dependent; therefore, specific studies and tests are required for specific frequency ranges and applications.

Some of the phenomena which affect radio signals and are studied in this program are:

1. Attenuation by atmospheric gases, hydrometeors (rain, snow, hail, clouds, etc.), or ionization.
2. Scattering by hydrometeors or irregularities in the refractive index of the lower atmosphere or ionosphere.
3. Refraction, ducting, and multipath resulting from atmospheric or ionospheric layers.
4. Dispersion resulting from frequency dependent properties of the atmosphere, ionosphere, and earth.
5. Scintillation of amplitude, phase, polarization, and angle of arrival resulting from turbulence and irregular structure in the atmosphere and ionosphere.
6. Reflection, scattering multipath, and lower atmosphere perturbations resulting from terrain and man-made structures.

The effect upon any specific system of the above phenomena is not only highly frequency dependent, but is also dependent upon the type of service required for the specific application.

One driving force behind the EM Wave Transmission Program is the need for more spectrum space. Therefore, this program provides models, techniques, and information to aid the system designer and frequency manager in their decisions for better spectrum use.

Experimental or theoretical determinations of radio wave transmission characteristics, or the channel transfer function, are reported in Section 3.1. Measurements of transmission media properties and analyses of collections of such data are included in Section 3.2. Section 3.3 describes the development and testing of models which incorporate the transmission information in engineering tools. Predictions of transmission characteristics and system performance are discussed in Section 3.4. Section 3.5 reports on applications of the knowledge and tools to specific problems of other government agencies, such as mine and forest service communications.

### SECTION 3.1. WAVE TRANSMISSION CHARACTERISTICS

Experimental determinations of the effect of the transmission media on electromagnetic wave transmission are reported in this section, in particular those effects produced by the atmosphere.

Multipath Fading Mechanisms and Link Reliability. The study of multipath fade mechanisms and resultant communications link reliability is based principally on experimental measurements obtained from propagation over two 23 km paths. A common transmitter is located at the Boulder Atmospheric Observatory (BAO) and the receivers are respectively located at Department of Commerce Radio Building and at the ITS Table Mountain field site north of Boulder. The transmitters are mounted on an elevator on the 300 meter BAO tower, which permits height-gain measurements in addition to fixed-level measurements. This provides a unique facility for the study of atmospherically induced multipath effects.

Operating frequencies at 9.6, 11.4, and 28.8 GHz were used in these experiments. Refractivity profiles were obtained at the transmitter terminal (BAO tower) during most height-gain runs using a device to record dry bulb and wet bulb temperatures and pressure, or a microwave refractometer. These profiles provide information on the presence and magnitude of variations in the refractivity index.

Observations were made for two years from June 1979 to June 1981. During this period approximately 200 height-gain observations were made, mostly in the early morning hours and on days when forecasts indicated promise of inversion layers. Figure 3-1 shows a height-gain measurement during a period on 20 June 1980 when substantial atmospheric layering occurred. One or both of the links were operated at fixed heights when height-gain observations were not being made.

The purpose of the fading studies is to determine the quality and reliability of terrestrial line of sight (LOS) channels for clear air conditions in the SHF and EHF (3 to 300 GHz) bands. Two mechanisms account for clear air fades: reflections of transmitted energy from terrain surfaces (ground) and obstacles (buildings, trees, etc.) and refraction through inhomogeneities of the atmosphere between the LOS terminals. These mechanisms are discussed and some of refractive fade observations are illustrated.

Reflected signal levels in a well designed link seldom produce fades of greater than 6 dB because of reduced reflection coefficients at low incidence angles and the reduced illumination of reflecting surfaces due to narrow antenna beamwidths obtainable in the upper portion of this frequency spectrum. Even though deep fades are generally not produced by surface multipath, they are particularly damaging to a channel used for wide band transmissions. Because of the usually long delay time (tens of nanoseconds) between the direct signal and the surface reflection, severe distortion occurs in the signal pass-

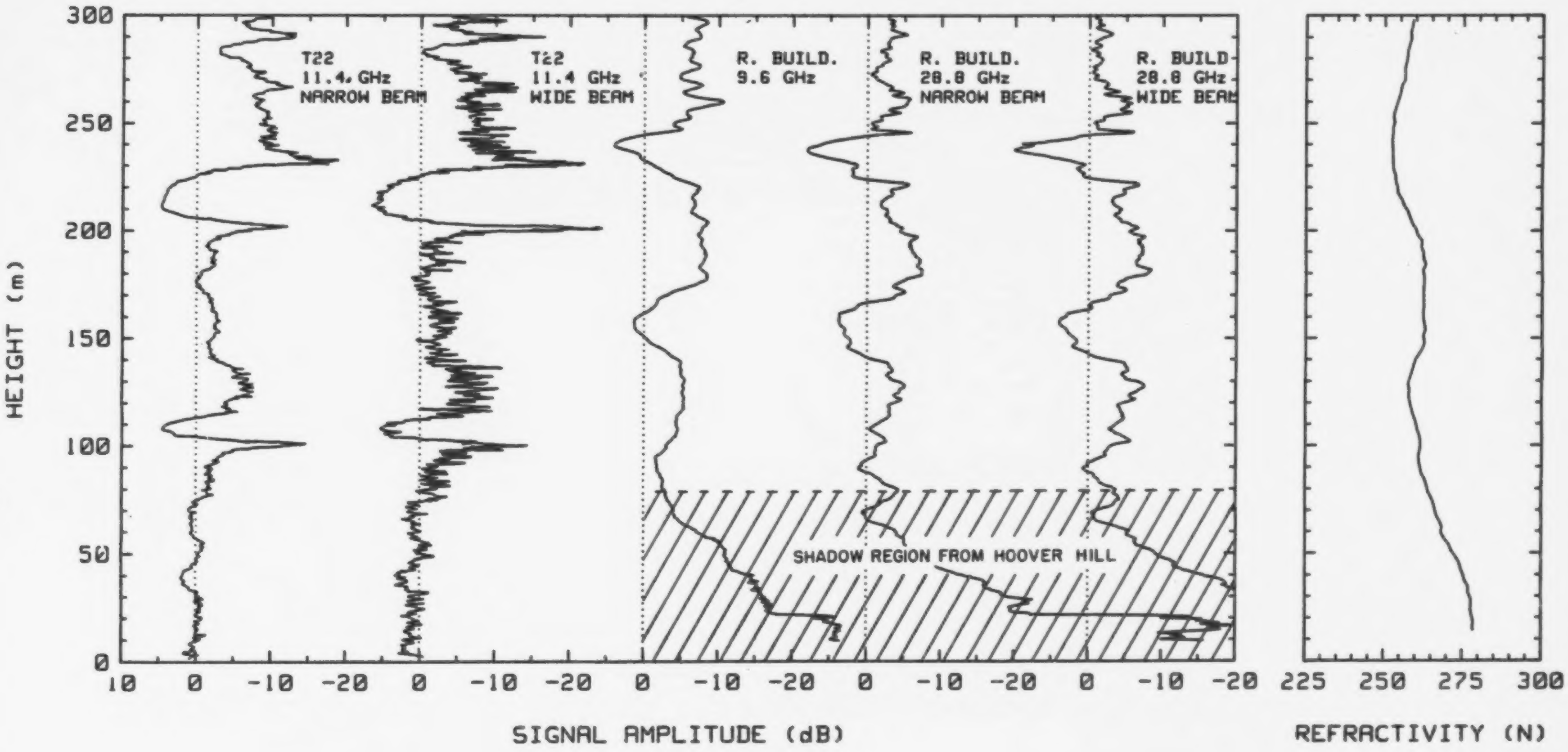

Figure 3-1. Height-gain measurement--signal amplitude relative to free space recorded over two 23 km paths on June 20, 1980.

band. This is particularly apparent in high data rate digital systems where intersymbol interference produces high error rates. The problem is enhanced when other fades reduce the direct ray, increasing the relative contribution of the long delay surface reflection.

When refraction or the bending of rays by the atmosphere occurs, several types of fades result. This refractivity produced fading is not well understood at SHF-EHF, and the identification of fade characteristics and effects on the channel performance was a primary goal.

A type of refractivity induced fade verified experimentally is an atmospheric multipath fade. This type of fade becomes more prevalent with increased frequency and occurs when two nearly equal rays form a path difference at the receiver, one-half wavelength out of phase. Atmospheric multipath is characterized by deep fades (> 40 dB) when other fade mechanisms are not present and is frequency dependent, as illustrated in Figure 3-2. Commencing at about 0405 (MST), a fade, enhancement, fade, and second enhancement occur on the 11.4 GHz channels ending at 0425 (MST). During this same time period, a much more rapid pattern of fades and enhancements occur on the 28.8 GHz channels. Atmospheric fades not only reduce channel signal to noise ratio (S/N), but can also produce distortion.

Fades defined as radio holes result when rays are bent away from the receiver or diverge. Anti-holes are the convergence of rays to produce a more concentrated field intensity. Radio holes are independent of channel frequency because the refractive bending is the same for all frequencies. Radio-hole fades reduce channel S/N, but do not cause distortion. The signal levels in Figure 3-3, show examples of radio holes and anti-holes. The fade on all four channels commencing at 0428 (MST) is caused by a radio hole and the enhancement, peaking at approximately 0505, resulted from a radio anti-hole.

Comparing fades on the channels using wide-beam antennas (5 and 10 degrees) with those using narrow-beam antennas (0.6 and 1.0 degrees) permits detection of a beam wander or a beam decoupling type of fade. Beam wander is a frequency independent type of fade, caused by ray bending away from the receiver, however, this mechanism does not produce channel distortion. No beam wander fades were observed over the path with the 0.3 degree resolution over a 2 year period as was true even when a 0.1 degree resolution was instrumented for 6 weeks by using the antenna lobe patterns and signal processing technique to obtain the resolution.

Scintillation is a refractive fading produced by small scale inhomogeneities. These fades, which occur often, seldom exceed 2 to 3 dB.

A full-wave type model for computing radio fields was used to predict height-gain observations from the associated refractivity profiles. The model is closely related to the geometrical theory of diffraction and was derived by ITS (Hufford et al.) Only qualitative agreement was found between the model predictions and the observations. This was attributed to the unrealistic assumption in the model that the refractivity profile was uniform along the path. During times of height-gain observations an acoustic sounder was operated to monitor atmospheric layer heights while the refractometer traveled through the layer. Both instruments showed rapid changes in the refractive layer height and gradient, however, a constant short period (10 minutes) gravity wave was apparent on the sounder indicating limited horizontal stratification.

Although strong refractivity gradients were observed at the BAO tower during many of the height-gain runs and during other observation periods using the tower instrumentation, the general absence of deep fades is attributed to the lack of sustained layering along the entire path. Of the 30 days, selected as having highest probability of inversion layers, for which height-gain measurements were taken, only on July 26, 1979 and June 20, 1980 were multipath fading and intense fading observed. On both of these days, moist air was present at the lower tower levels, covered by dry air above.

Other than the two brief periods when atmospheric multipath fades exceed 20 dB, refractive induced fades seldom exceed 10 dB. Only the long delay, but small in amplitude, ground multipath signals will produce distortion to a wide band channel. To evaluate the extent of this distortion a 1 Gb/s phase modulated system (1.5 GHz bandwidth) will be added to measure discrete multipath components and record the resulting bit error rates.

During this same study period, no link outages were observed due to fades caused by precipitation. A typical and average distribution of rain and snowfall occurred.

These observations indicate that communications links not affected by multipath signal delays would have performed with a very low outage time.

## SECTION 3.2. CHARACTERISTICS OF THE TRANSMISSION MEDIA

This section is concerned with the study of transmission media to help those who design, construct, or use telecommunication systems to better understand the characteristics of the media and their effects on radio signals. We first discuss the nonionized atmosphere and then the ionosphere.

### 3.2.1. Atmospheric Characteristics

MM Wave Attenuation. Moist air is characterized for the frequency range of 1 to 1000 GHz as a nonturbulent propagation medium described by meteorological parameters. An adequate spectroscopic data base for air consists of three terms: (i) resonance information for 29 $H_2O$ lines up to 1097 GHz and 44 $O_2$ lines up to 834 GHz in the form of intensity coefficients and center frequency for each line; (ii) an empirical water vapor

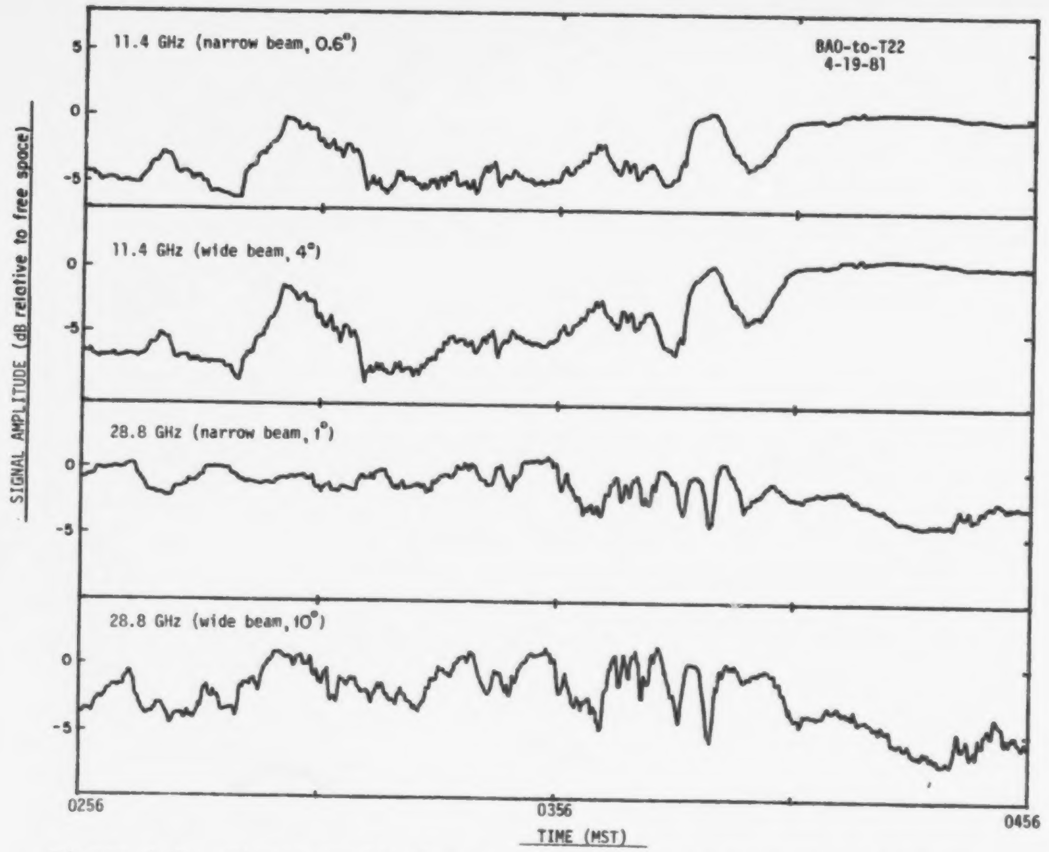

Figure 3-2. Signal amplitudes recorded over a 23 km path on 4/19/81.

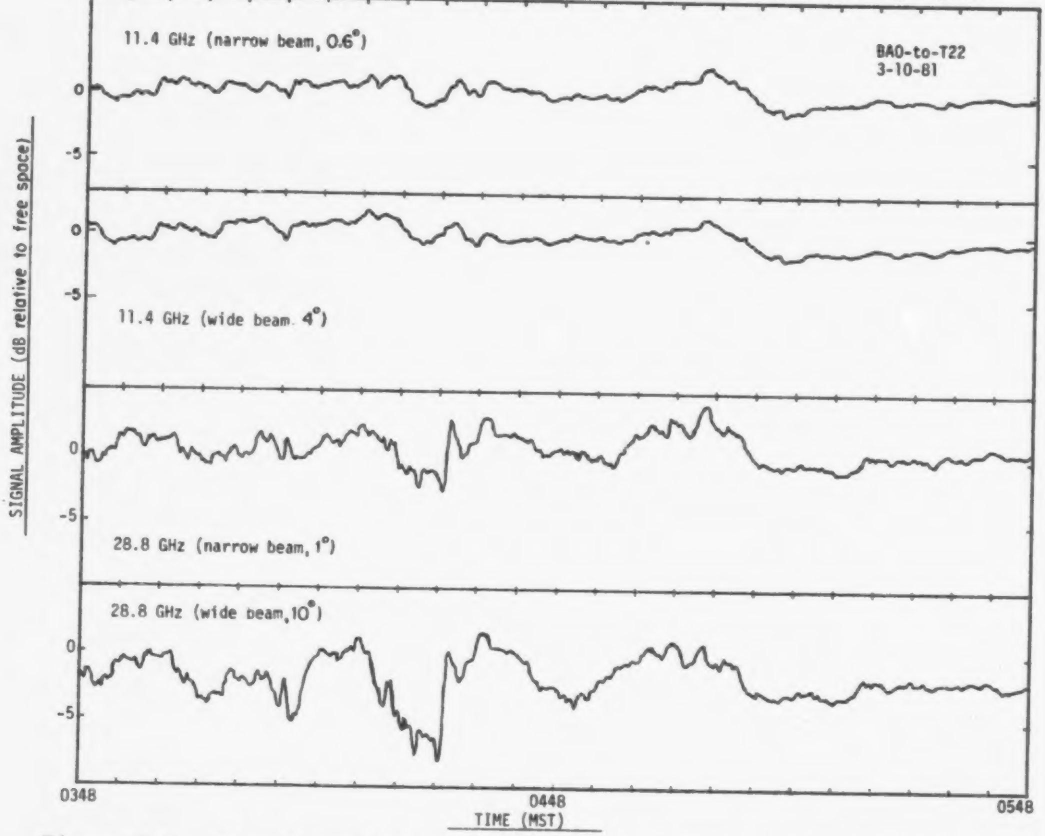

Figure 3-3. Signal amplitudes recorded over a 23 km path on 3/10/81.

continuum spectrum; and (iii) a liquid water attenuation term for haze and cloud conditions. This data base is the heart of a dual computer program which calculates and plots attenuation rates (dB/km) and refractive dispersion (ppm).

The first part covers the troposphere and requires pressure, temperature, relative humidity, and cloud liquid water concentration as input data. Figure 3-4 gives four examples, which are representative of conditions in a mid-latitude climate.

Part two addresses isolated line behavior in the mesosphere wherein the geomagnetic field strength H is an additional input parameter due to the Zeeman effect of the $O_2$ molecules. Each oxygen line splits proportionally with H into numerous sub-lines, which are juxtaposed to form a Zeeman pattern spread over a megahertz scale. Patterns of three main polarization cases are considered. Various typical examples for a model atmosphere (Figure 3-5) demonstrate the utility of the approach and provide new information on Zeeman attenuation in the mesosphere by oxygen.

Cumulative Behavior: A standard example for an inhomogeneous medium is the one-way zenith response through the U.S. Standard Atmosphere 1976. Figure 3-6 displays the cumulative attenuation A for which 60 height levels up to h = 100 km are summed. Three humidity profiles $\rho(h)$ were used to model RH = 5, 50, and 100% in each of 26 height layers between h = 0 and 8 km. The RH drops rapidly below 1% above h = 8 km. The frequency range 55 to 65 GHz is opaque (A>30 dB) for any system attempting to look through. The transmittance is measurable when the atmosphere is somewhat transparent (A<30 dB), and it can be determined either by the absorption of a signal coming from the outside (sun emission, satellite beacon) or by thermal emission from the air mass.

We cooperated with N. Feldman (formerly RAND) to model height-dependent atmospheric attenuation for the frequency range 50-70 GHz and a paper will be presented at the Inst. Telemetering Conference, Oct. 13-15, 1981 in San Diego. An NTIA report is in preparation to present more than 1400 examples of attenuation/dispersion curves exhibited by various model atmospheres (h=0-100 km, f=1-1000 GHz, RH=0-100%, H=0-1 Gauss).

The problem of excess water vapor absorption (EWA) in the millimeter wave window ranges was reviewed in detail. A summary of the findings was presented to the XXth General Assembly of URSI (August 10-19, Washington, D.C.) by Prof. P. DeLogne, chairman of URSI-F Working Party on EWA. A report authored by P. DeLogne and H. Liebe, entitled "Attenuation by oxygen and water vapor in the atmosphere at millimeter wavelengths", was produced.

Prof. M. Mizushima, consultant, introduced some new theoretical ideas in predicting electric dipole transitions in the species $^{16}O^{18}O$ and $^{14}N^{15}N$. Stronger absorption lines for $^{16}O^{18}O$ are predicted at 78.9, 98.3, 135.7, 162.8, 217.1, 219.6, 244.2, etc. GHz and for $^{14}N^{15}N$ at 115.3 and 230.7 GHz. The correct magnitude of the dipole moment is not known; however these lines have the potential to explain some observed, but yet unidentified, line features in the mm-wave windows.

Experimental Effort: The spectrometer cell, simulating a 0.2 km radio path at 140 GHz, was completed and tested for its humidity behavior.

Based upon the results of Humidity Test I, the initial apparatus had to be redesigned. Also, a stronger pump (700 vs. 250 grams/hr) water removal) and a 4-probe internal temperature scanner were added. Measurements at RH>95% generally require a stability of better than ± 0.005°C. The precise control of temperature proved to be most important. A Humidity Test II is in progress yielding desired results.

The Fabry-Perot resonator was tested at 140 GHz. The loaded Q-value is quite high (48500) yielding an effective path length of 165 meters, which assures excellent detection sensitivity. The resonator is mounted inside the humidity chamber (Figure 3-7) and the spectrometer was optimized (± 0.2 dB/km detection sensitivity) for operation at 140 GHz. The output signal is captured and displayed with a digital waveform processor; up to 40 waveform data can be analyzed and stored indefinitely for comparison. Attenuation and refraction (frequency shift) measurements of up to 512 data pairs are made under program control.

The first high humidity data were obtained. The result of 9 + 2 dB/km average of over 100 individual data points in saturdated air (RH ≈ 100%) at 140 GHz is quite high. The prediction model yields only 2.6 dB/km. A square law was assumed for the detector. The work continues.

Millimeter Wave: Propagation through vegetation on Colorado's east slope. Measurements of millimeter wave propagation in vegetation were made for the U.S. Army Communications Electronics Command. The objective of the project was to obtain information on signal loss, spatial, depolarization, and scattering characteristics for propagation through both deciduous and conifer groves for a variety of foliage density and moisture content at three frequencies in or near the millimeter wave band. One of the important needs for this information is in the assessment of the feasibility of using trees for camouflage of one or both terminals of a communications link.

The instrumentation for this measurement program was mounted in four-wheel-drive vans for mobility in rough terrain. The rf components are supported on erectable track-mounted carriages to permit ready adjustment of height above ground. In addition, the transmitter mounting permits two meters of horizontal travel to allow variability along this axis.

The directional antennas scan in elevation and azimuth angle by a remote-controlled positioner at the receiver terminal to provide data on the intensity of off-angle scatter from foliage and ground reflection effects.

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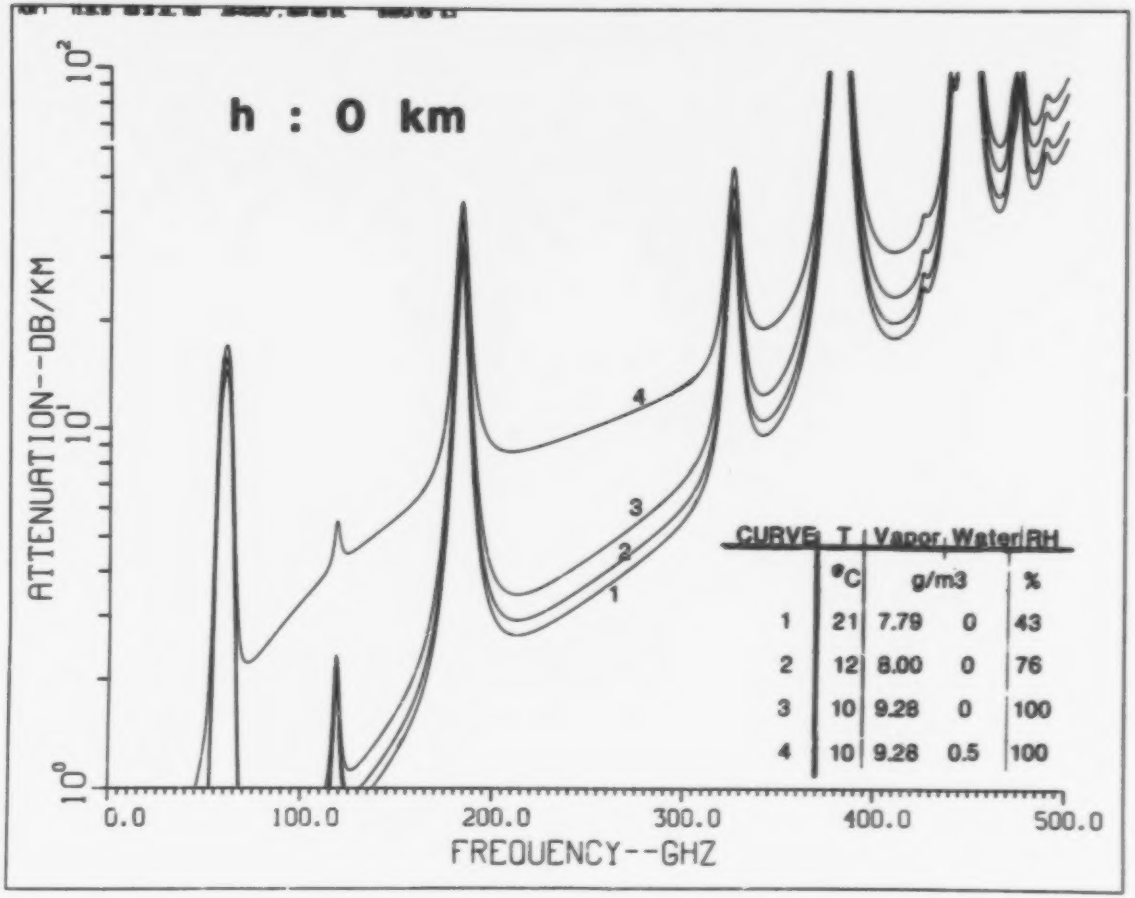

Figure 3-4. Attenuation α in dB/km of typical examples for moist air at sea level over the frequency range 30 to 500 GHz including fog with 0.5 g/$m^3$ liquid water content.

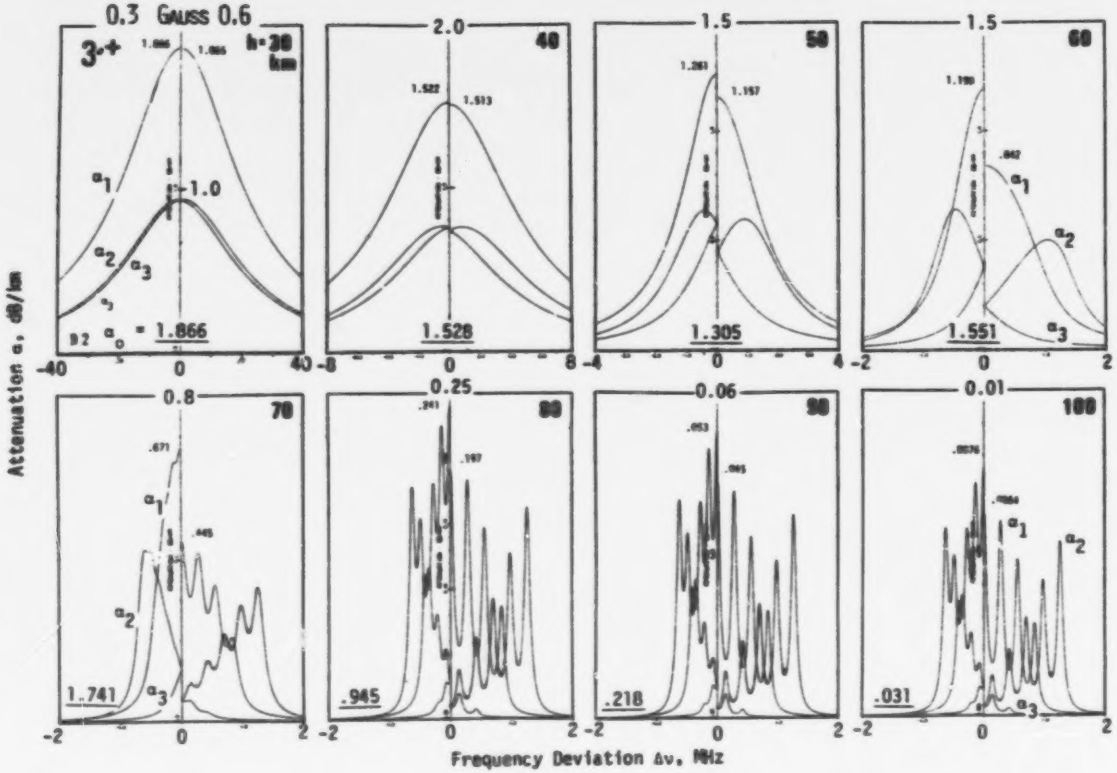

Figure 3-5. Zeeman attenuation patterns of the oxygen microwave line K = $3^+$ for altitudes h=30 to 100 km. Each frame displays $\pi(\alpha_1)$, $\sigma^+(\alpha_2)$, and $\sigma^-(\alpha_3)$ patterns for the magnetic field strengths, H=0.3 (left hand) and H=0.6 Gauss (right hand). The maximum attenuation rate $\underline{\alpha}_o$ is that of the isolated unsplit line (H=0). The values of $\alpha_1(\nu_o)$ in dB/km are for 0.3 and 0.6 Gauss.

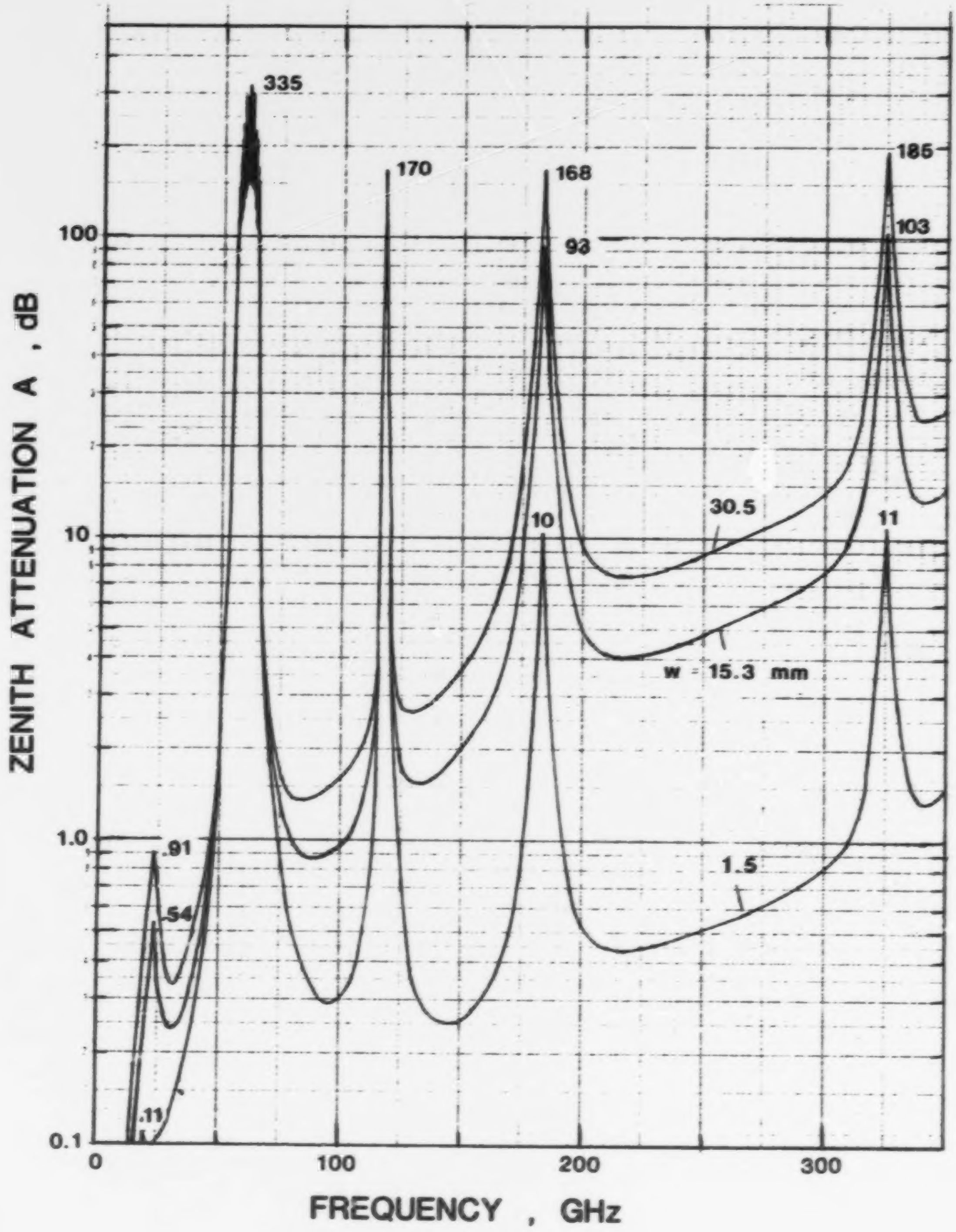

Figure 3-6. Zenith attenuation A through the U.S. Standard Atmosphere 1976 for dry (RH=5%), moderate (50%), and humid (100%) air over the frequency range, 10 GHz to 300 GHz (EHF). The relative humidity RH was assumed to be constant for h=0 km to 8 km. The total precipitable water vapor is given by w.

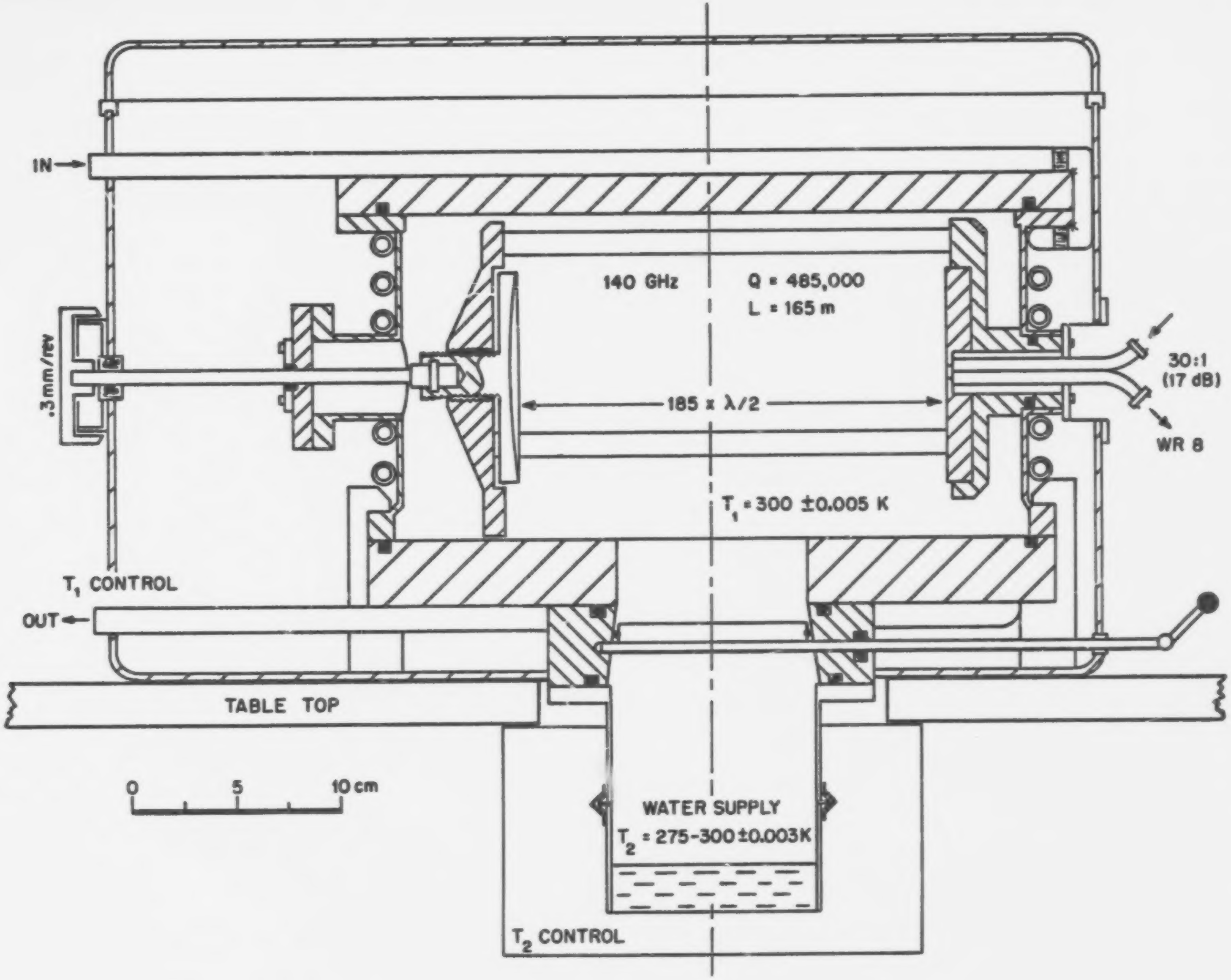
IN
140 GHz
Q = 485,000
L = 165 m
.3 mm/rev
185 x λ/2
30:1
(17 dB)
WR 8
$T_1$ = 300 ±0.005 K
$T_1$ CONTROL
OUT
TABLE TOP
0
5
10 cm
WATER SUPPLY
$T_2$ = 275-300 ±0.003K
$T_2$ CONTROL

Figure 3-7. Fabry-Pérot resonator simulating a 165 m radio path at 140 GHz and mounted inside a temperature-controlled humidity simulator.

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Three frequencies, namely 9.6, 28.8, and 57.6 GHz, were used simultaneously to obtain frequency dependent data to aid in developing transmission loss models for specific types of vegetation. Both vertical and horizontal antenna polarization are mechanically selectable at each terminal, which permits measurements for each case, including cross polarization.

The data recorded from these measurements consist of received signal amplitudes from both azimuthal and elevation scans at transmitter and receiver heights from 1 to 9 meters above ground. The transmitter antennas were normally fixed at a zero angle (on-path) pointing and the receiving antennas were scanned at ± 20° in the azimuthal plane and ± 15° in the elevation plane.

The significant results and observations from this study are listed in the following summary statements with specific illustrations shown in Figures 3-8 through 3-11:

1. The measured signal loss (dB/m) through trees in foliage exceeds predicted loss obtained from extrapolation of data from numerous sources at frequencies between 100 and 9000 MHz. These extrapolated values indicate only 1/3 to 1/10th the dB/m loss measured in the frequency range of 10 to 60 GHz. The term dB/m means dB loss per meter of measured foliage depth on a path, independent of the total path length. These studies have indicated a need to establish a method for determining depth of foliage. This aspect must be examined when comparing results.

2. Diffraction theory has a $\sqrt{f}$ dependence which sometimes is used to predict vegetation loss (dB/m) at higher frequencies. Although our results show that vegetation losses clearly increased (on the average) at these frequencies, the ratio was less than $\sqrt{f}$ over the 10 to 60 GHz frequency range. Normalized losses due to vegetation (dB/m) show a trend to decrease as the foliage path is lengthened, which appears consistent with measurements at lower frequencies.

3. The measured vegetation loss in nearly all cases, as observed in Figure 3-8, was less at the 1 and 2 meter heights than at heights greater than 2 meters. This is the result of no leaves or sparse leaves at the 1 and 2 meter height and the general absence of underbrush on the sites used for these tests. Also, vegetation loss difference as a function of antenna polarization was very slight through trees, whereas for tall grass, horizontal polarization clearly provides less loss. When comparisons of vegetation loss were made of deciduous groves, with and without foliage, the groves in summer foliage produced about 3 times as much loss in dB/m as the same groves in their defoliated state. Figure 3-9 shows an example of these observations.

4. An important factor is the dependence of received signal on spatial variance. Signal amplitude variations as large as 42 dB, see Figure 3-10, and typically 30 dB were observed for small displacements (≈ 25 cm) of the transmitter antennas in either the horizontal or vertical plane. There is considerable evidence that these deep fades are results of two relatively strong multipath signals adding destructively. Exposed (free of leaf cover) trunks and branches appeared to be the source of the multipath.

5. Observations during windy periods (15 to 20 km/h) on a path with 10 or more meters of foliage depth produced signal variations (scintillations) of up to 15 dB with periods of less than 5 seconds. In addition, 8 dB fades of longer periods (1 to 5 minutes) were noted in gusting winds. The time series records in Figure 3-11 illustrate typical scintillations.

6. An increase in vegetation loss was noted during a rain on a single observation when water covered, or droplets formed on, leaves and branches of a willow tree. The signal loss increase was 3 to 5 dB at 9.6 GHz and 15 to 20 dB at 28.8 GHz; however, these maximum losses occurred several minutes after the shower started, indicating perhaps a delay in wetting of leaves and branches contributing to propagation in sheltered regions. Moisture condensation prevented a measurement at 57.6 GHz. A wet snow fell during a conifer path observation and much of it stayed on the branches; however, no detectable signal change was noted.

7. Depolarization of signals propagated through exposed tree trunks showed less change than through leafy foliage where depolarized signal level increased by as much as 20 dB.

8. Lateral wave propagation and tree top diffraction enhancements were not detected; however, measurements were not conclusive due to uncertainties in canopy height, canopy roughness, and path geometry.

9. For a path with high loss due to foliage, a stronger received signal was observed when a common off-path volume (clear of tall trees) was illuminated. In the observed case, a common scatterer, perhaps a bush or terrain feature in a clearing, produced a side-scatter signal level higher than the direct-path signal.

10. Direct backscatter measurements from a willow and a pine grove produced an equivalent spherical radar cross section range of 0.008 and 0.5 square meters, depending on frequency.

11. On a defoliated path, a comparison of narrow-beam to wide-beam illumination showed a slight decrease in vegetation loss and much reduced off-angle scattering components. In which case, also, on a defoliated path, no detectable difference was measured when siting a narrow-beam terminal near foliage and a wide-beam terminal in the clear compared to the reverse of these terminal locations.

Millimeter Wave: Urban Propagation Study. A measurement of millimeter wave propagation characteristics in areas surrounded by buildings in a city environment with principal

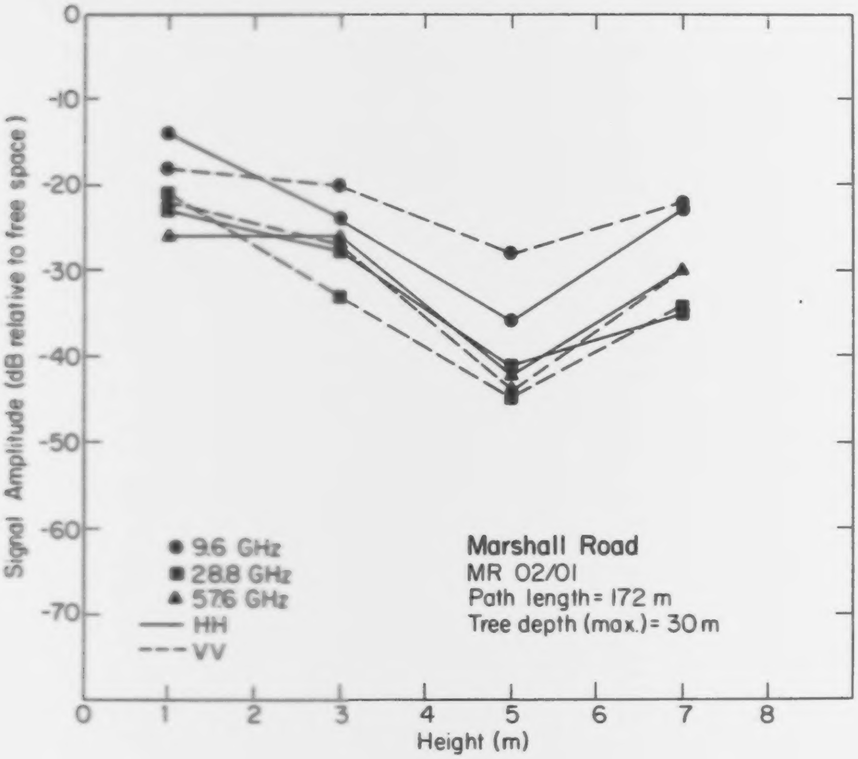

Figure 3-8. Signal amplitude as a function of height for a cottonwood grove (HH polarization and VV polarization).

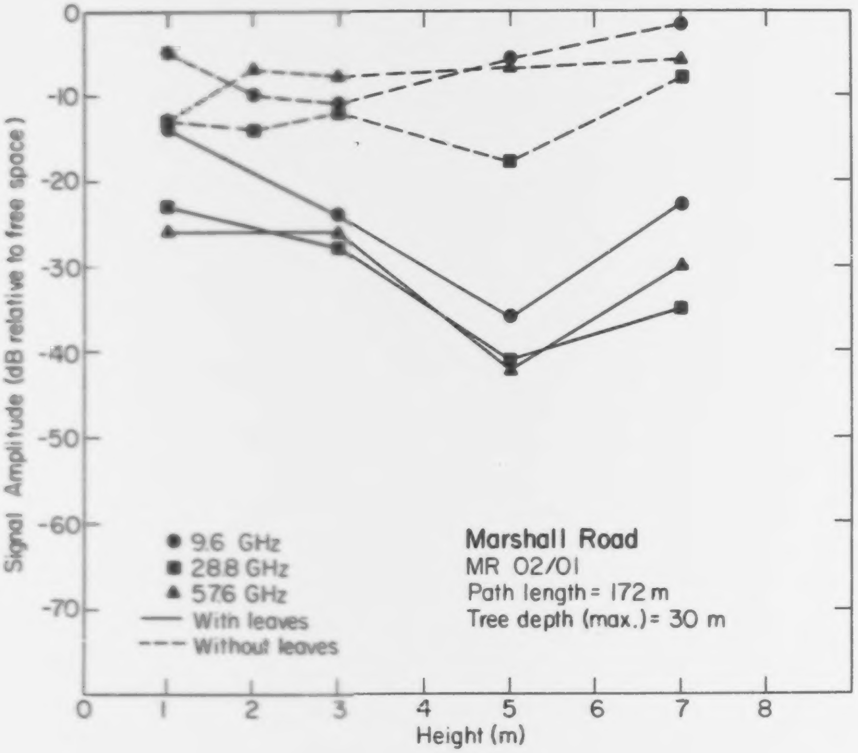

Figure 3-9. Signal amplitude as a function of height for a cottonwood tree grove, with and without foliage (HH polarization).

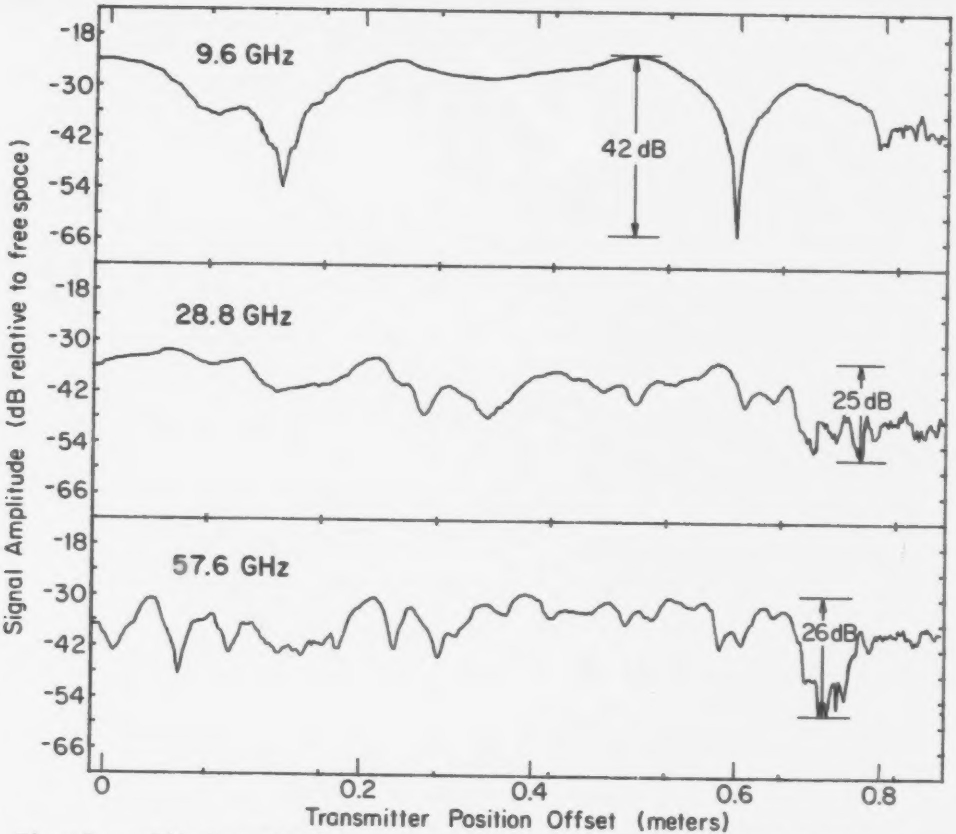

Figure 3-10. Signal amplitude relative to transmitter antenna horizontal displacement. (MR01/01, path length = 152 m, height = 1 m, tree depth = 40 m, polarization = VV).

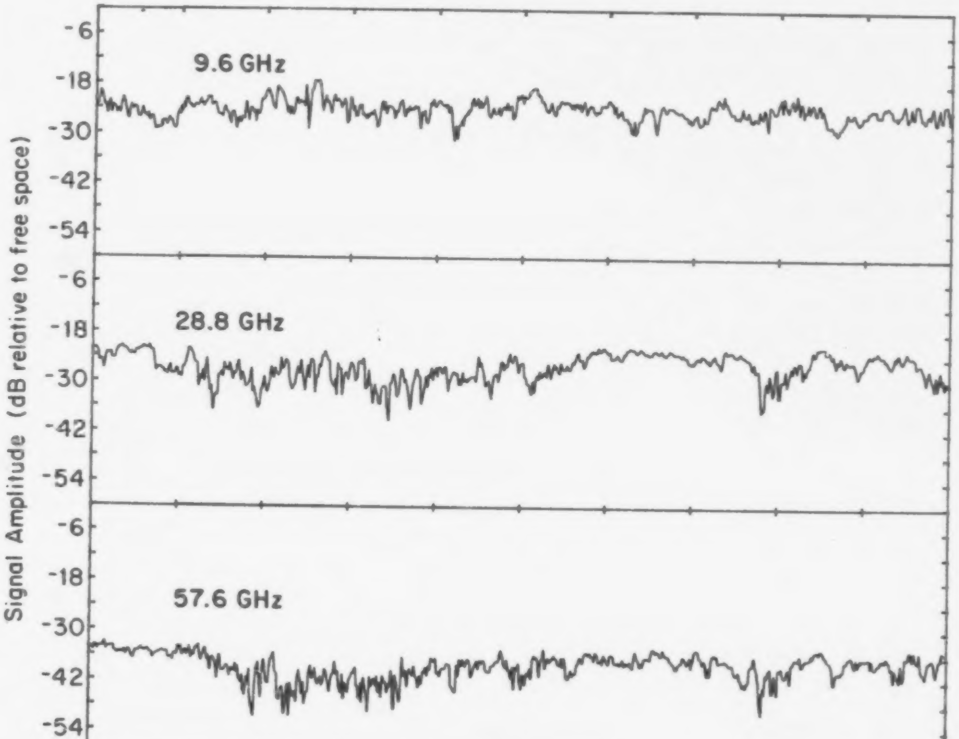

Figure 3-11. Time series records of received signal amplitude during windy conditions.

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emphasis on the evaluation of voice intelligibility and usable bandwidth or digital data rate capability as a function of position of terminals is in progress for the U.S. Army Communications-Electronics Command.

The probe frequencies for this study are the same as for the propagation through vegetation work: 9.6, 28.8, and 57.6 GHz. A van will house the receiver terminal and a portable dolly will be used to transport and position the transmitter.

Scans of both a narrow-beam receiver and a 10° beam-width transmitter will be performed to record all signal paths with levels within 30 dB of the direct path signal level. The receiver will perform a rapid continuous scan and the transmitter scan will be stepped in 10° increments. Also, measurements will be conducted on non-line-of-sight paths to levels of the order of -70 dB relative to the free space signal level to determine covertness characteristics in an urban environment.

The data obtained from the scans indicated above will provide values for coefficient of reflection from various surfaces of buildings, such as concrete aggregate, glass, metal siding, etc. These reflection coefficients, in addition to antenna patterns and molecular absorption data, will be used in a multipath propagation equation to calculate a family of plots showing predicted signal intensity. These signal intensity curves will be calculated and plotted, using a desk top computer, as a function of antenna beam width, frequency, distance between terminals, and terminal position.

It is then proposed that U.S. Army 38 and 60 GHz handheld communicators be used to measure specific paths and compare these results to the values predicted in the computer plots using propagation equations derived for the same paths. Non-line-of-sight paths will also be measured and compared, noting reflected signals from flat surfaces as well as diffraction from edges of obstructions, such as corners of buildings. In the latter case, the measured levels will be compared to knife-edge diffraction pattern models in the shadow regions.

Also with the handheld communicators, voice intelligibility tests will be conducted where readability is questionable. For known multipath delay and signal amplitude conditions, standard word lists will be used to score the intelligibility. It is believed doppler flutter from moving vehicles will be a major source of unintelligibility and will provide a complication in measurements independent of flutter. However, measurements will be made at periods of little or no traffic, such as predawn, or in areas where vehicular traffic is not permitted. When measurements can not avoid traffic situations, the effects can be separated, resulting in information of flutter characteristics due to motion of vehicles. This information will be useful in scenarios with vehicles in combat.

MM-Wave Propagation Review. At the specific request of and funding by the Electro-optical Division, Atmospheric Sciences Laboratory, White Sands Missile Range, NM, a comprehensive review was undertaken on the effect of solid and melting hydrometeors on terrestrial SHF radio propagation. This study was augmented by an excellent computerized database search conducted by the Boulder Laboratories Library staff. Hydrometeors are the various forms of precipitated water naturally present in the atmosphere. To date, non-liquid forms of atmospheric water have been included in papers on rain, the most prevalent form of hydrometeors, and a separate study of this type was necessary for cold weather measurements being conducted in New England.

The results of this project were published as U.S. Army ERADCOM R&D Technical Report ASL-TR-0092, July 1981, "Effect of Hail, Snow, and Melting Hydrometeors on Millimeter Radio Waves." This report is a companion to the earlier ASL-TR-0049, January 1980, "Atmospheric Effects on Millimeter Radio Waves," by the same author dealing mostly with rain, which is of primary importance because of its ubiquity and high dielectric constant at millimeter wavelengths.

In examining 52 selected papers which are referenced in the technical report, hail and sleet were found to be more amenable to theoretical calculations and laboratory experimentation of attenuation and backscatter than snow and graupel due to their simpler approximations of particle shape and dielectric constant. However, field measurements on hail and sleet are virtually nonexistent, whereas data on the behavior of millimeter waves through falling snow - notably attenuation - has been characterized for various frequencies, snow condition, and snowfall expressed in equivalent rain rate or liquid water content.

These measurements by several authors are shown as regression curves in Figure 3-12 of attenuation in dB per km vs. snowfall as equivalent rain rate in mm per hour. For comparison, rain attenuation for four selected frequencies at 1 mm per hour is shown as dots. According to the figure, the open literature tends to reveal that snow attenuation at millimeter wavelengths increases with frequency, snowfall rate, and snowflake liquid water content.

In retrospect, we see that a lack of field data on the shape, size, dielectric condition, and number per unit volume of non-liquid hydrometeor particles as a function of space and time makes comparison between theoretical calculation and experimental measurement difficult. This is not the case for rain at the longer millimeter wavelengths as seen from the earlier technical report.

Melting snow has been shown to affect millimeter waves to the same extent as rain, and the report recommends that priority be given to measurements in this area over hydrometeors of lesser liquid water content. Along these lines, comparative treatment of melting snow and rain during the same event

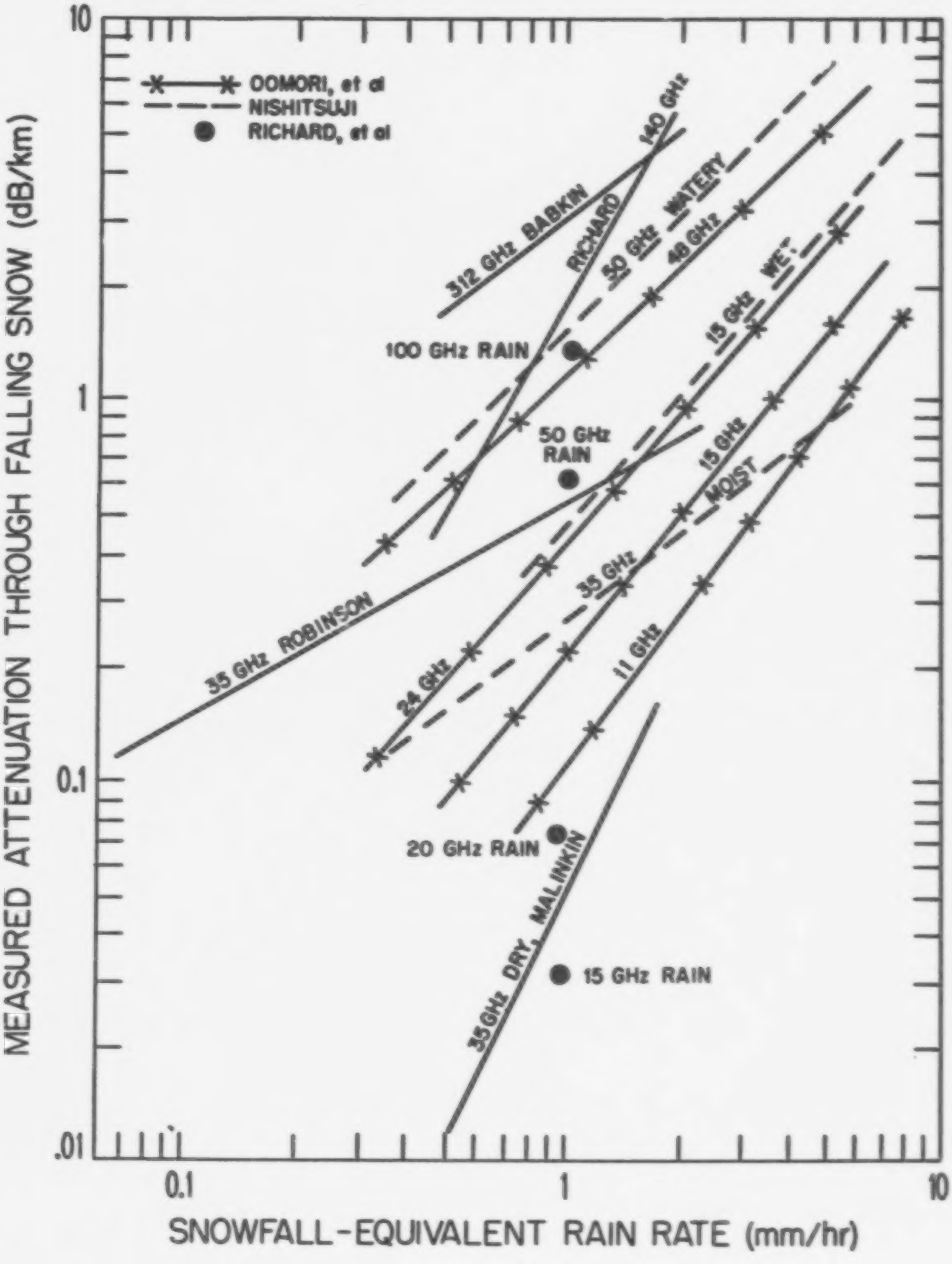

Figure 3-12. Measured attenuation through falling snow.

at the same frequency and along the same path are especially valuable because the effect of rain is relatively well understood up to about 140 GHz.

The results of this project and technical report have been incorporated into the planning and execution of U.S. Army ERADCOM's SNOW I measurements in Vermont during January 1981.

Trace Gas Attenuation of Air. The use of systems operating at 35 GHz is anticipated for a low altitude missile defense. Such systems must operate in environments that could be disturbed by nuclear bursts. Of particular concern is the disturbed chemistry exterior to the fireball. The molecules $H_2O_2$ (hydrogen peroxide), $HNO_3$ (nitric acid), and $HNO_2$ (nitrous acid) have been identified as having increased concentrations (>100 ppm/v) following these events, which could lead to substantial absorption (>0.25 dB/km) near 35 GHz, in addition to that caused by $H_2O$ and $O_2$. A laboratory experiment has been prepared to measure, at room temperatures, absolute attenuation-versus-pressure rates of the identified molecular species. The difficulties with the experiment lie in the corrosive, absorptive, and hazardous nature of the test vapors and in achieving (i) a high detection sensitivity (<0.1 dB/km) with absolute calibration and (ii) a verified concentration inside the test cell.

Measurements of attenuation and refraction were performed on fairly pure vapors at low pressures (<3 torr) and on mixtures at atmospheric pressures (>600 torr) using $N_2$ as the inert, loss-free host gas. The performance of the spectrometer was adequate to obtain the desired results. The molecules $H_2O$, $NO_2$, $H_2O_2$, $N_2O$, and $HNO_3$ produced insignificant attenuation (<0.1 dB/km) up to concentrations of 500 ppm/vol in 1 atm of air.

Model calculations of attenuation for sea level air were performed over the frequency range 20 to 50 GHz: (i) for the temperature range -20° to 40°C and relative humidities RH = 0, 10, 50, 100%, and (ii) for 27 to 727°C (300-1000°K) simulating air heated by an explosion. Examples of the latter are depicted in Figure 3-13.

### 3.2.2. Ionospheric Characteristics and Effects

Defense Meteorological Satellite HF Observations. In the late spring of 1977 (as part of the Defense Meteorological Satellite Program (DMSP)), the Air Force launched a satellite that was equipped with an HF radio-noise receiver. The satellite was launched into an almost sun-synchronous dawn/dusk orbit at about 500 n mi (860 km). In mid-summer of 1979, a second DMSP satellite containing an HF radio-noise receiver was launched. This satellite was launched into a sun-synchronous noon/midnight orbit, also at about 500 n mi. Both satellites were equipped with instrumentation that provided observations of HF signals between the frequency range of 1.2 to 13.9 MHz. The receiver continuously sweeps through this frequency range in 100 kHz steps in a total time of 32 seconds. Each satellite moves approximately 7 km per second, which means that a value of signal strength can be obtained about every 200 km along each satellite orbit. Both the dawn/dusk and noon/midnight satellites were equipped with tape recording systems, making it possible to obtain observations continuously throughout the orbit.

The electromagnetic environment with the satellite is rather noisy for an experiment designed to provide detailed information about the HF environment at the satellite height. Also, operational considerations prohibited obtaining a knowledge of the performance characteristics of the antenna in the topside ionosphere. It is for this reason that the results discussed herein will be presented in terms of the receiver terminal voltage as opposed to the more conventional field strength of noise temperature. In a later section, the relationship between the measured receiver terminal voltage and the actual signal power density at the satellite height will be given.

Figure 3-14 provides an indication of the type of data obtained from the DMSP HF receiver. Shown in the figure is the receiver output voltage as a function of frequency during a full scan of the receiver. It is apparent that, at the higher end of the frequency scale, the data are more erratic and have higher values than at the lower end. This feature is attributed to electromagnetic energy being received at the satellite from various sources on the earth's surface at frequencies above the subsatellite critical frequency. For frequencies below foF2, the ionosphere effectively shields the receiver from ground-based transmissions.

Data of the type shown in Figure 3-14 have been combined and used to generate maps of receiver output voltage as a function of satellite location. For each satellite, observations were grouped according to month, time of day (noon, midnight, dawn, or dusk), and frequency. Figure 3-15 shows smoothed contours of the HF noise observed at 11.8 MHz during the month of April 1978 during the period of local dusk. The frequency 11.8 is allocated to the HF broadcasting services. It is found that the highest values of the contours are associated, in general, with the area of the ionosphere illuminated by high-powered, ground-based international broadcasting emitters.

The results presented by Rush et al. (1980, Satellite Measurements of the HF Radio Environment in the Topside Ionosphere, Radio Sci. 15) suggest that the source of the HF signals observed by the DMSP satellite was discrete ground-based transmitters. Contours of receiver output voltage tend to be centered above areas of the globe where emitters assigned to specific telecommunication services (maritime, fixed, and broadcasting) are expected to be located. This being the case, it should be possible to use the observations from the DMSP satellites to study seasonal and diurnal variations in the global representation of receiver output voltage and relate these variations to corresponding

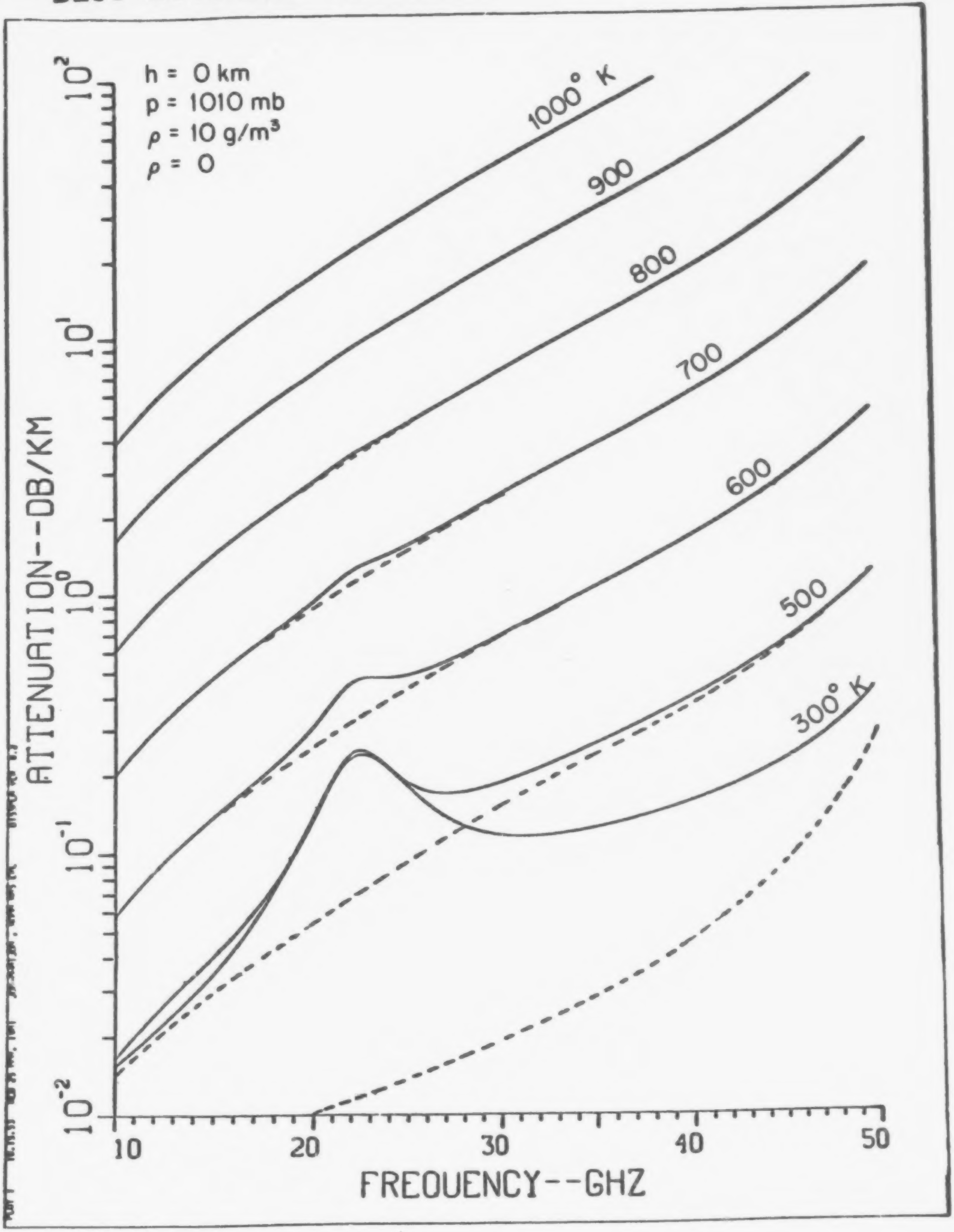

Figure 3-13. Modeling attenuation $\alpha$ (dB/km) for moist air (absolute humidity $\rho = 10$ g/m$^3$) at elevated temperatures 300 to 1000°K over the frequency range 10 to 50 GHz.

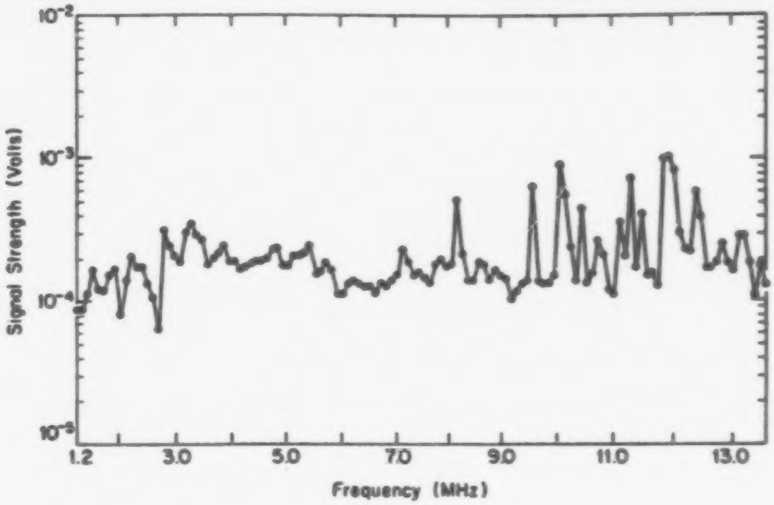

Figure 3-14. Signal strength (in volts) as a function of frequency observed by the DMSP HF receiver above a location of 40.4°N and 265.8°E on July 27, 1977, at 1236 (UT).

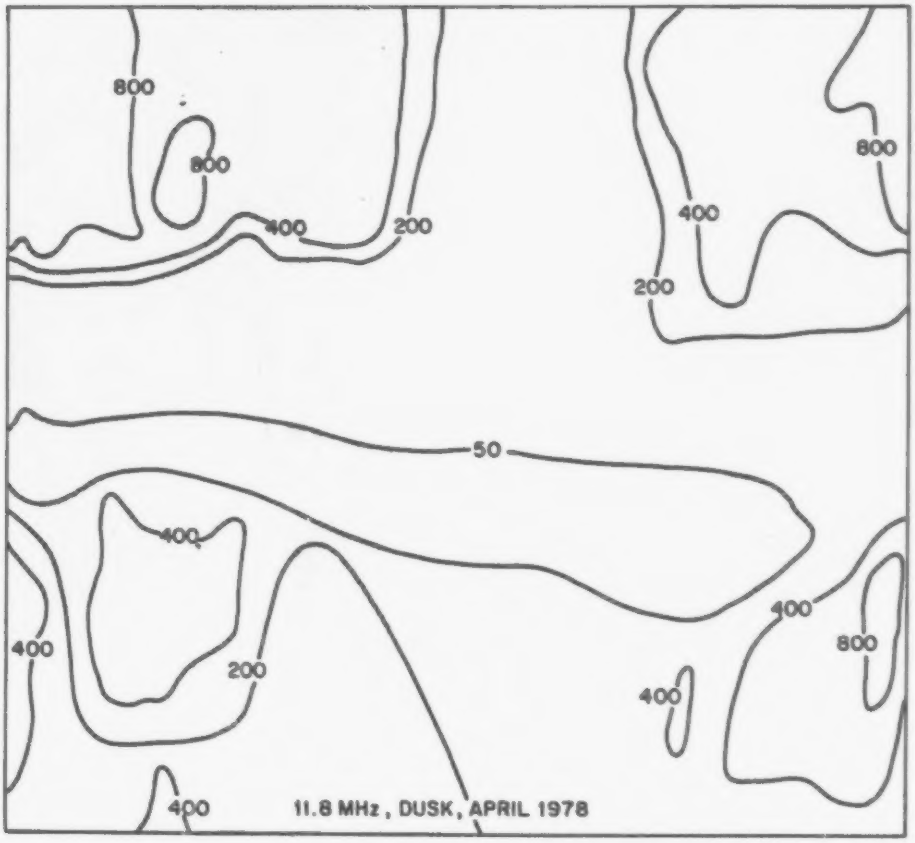
800
800
400
200
400
200
800
50
400
400
200
400
800
400
400
11.8 MHz, DUSK, APRIL 1978

Figure 3-15. Average global behavior in the topside ionosphere of the HF radio environment at local dusk for 11.8 MHz during April 1978. Contours are receiver output voltage (millivolts x $10^{-3}$).

seasonal and diurnal variations in the operation of ground-based telecommunication systems.

Global maps such as illustrated in Figure 3-15 have been produced for a number of frequencies for the months of April 1978, September 1979, and December 1979. In addition, for September 1979 and December 1979, maps were developed for local times surrounding dawn, dusk, noon, and midnight, since two DMSP satellites containing HF receivers were orbiting during those months. Frequencies of 6.1, 8.5, 9.6, 11.8, and 12.5 MHz were selected for study. The frequencies of 6.1, 9.6, and 11.8 MHz are allocated to the broadcast service, and the frequencies of 8.5 and 12.5 MHz are allocated to the maritime mobile service. In all instances, there was little or no seasonal dependence that could be discerned for the results obtained above North America, Europe, and Asia. For a given month, the maps obtained for the four local time periods of dawn, dusk, noon, and midnight tend to reflect the influence of the ionosphere upon the satellite observations. Frequencies of 9.6 MHz and lower tend to show an absence of signals during the noon period. This is consistent with the observation that, during September and December 1979, the critical frequency of the F2 layer, for foF2, was greater than 9.6 MHz during local noon for most locations around the globe. Radio waves incident upon the ionosphere from below can only be observed at a satellite located above the height of the F2 region peak if the frequency of the radio wave is greater than the subsatellite critical frequency.

HF Antenna Simulation. The Institute undertakes studies of the ionosphere in order to predict ionospheric propagation effects. The basic prediction program used for assessing ionospheric propagation conditions (IONCAP) is intended to provide the necessary data for the design of HF communication systems and for selection of frequency complements for such systems. A substantial effort has been devoted to the development of antenna models and a program code to be used with the IONCAP program. The major intent is to create an antenna package to be used with the HF sky-wave predictions.

Radio waves under consideration here have been reflected from the ionosphere and thus have traveled a considerable distance. This allows the problem to be viewed as two parts: (1) the local effect of the ground at the transmitting site on the antenna, and (2) the local effect of the ground at the receiving site on the antenna. Further, the assumption of plane-wave reflection is justified for this sky-wave case.

The analysis of the antenna models was broken into two logical subdivisions:

(a) The exterior (radiation) problem, which deals with the interaction of the antenna with the propagation medium; and

(b) the interior (circuit) problem, which deals with the interaction of currents, voltage, etc. within the antenna system itself.

The solution to the interior problem is implemented as precalculated curves or as measured curves where available. The exterior problem is implemented using the equations as developed by ITS. For arrays of dipoles, the practice of expressing the array equations as that of the resonant dipole element and a reduced array factor is used. This procedure results in a computer code which is quite stable and fast in running time. There are no matrix inversion routines nor any use of the complex arithmetic routines.

The models for the log-periodic dipole arrays (horizontal and vertical) have been redone. The basic method used was to incorporate measured curves of the variation of the parameters entering into the solution of the interior problem. Where gaps existed in the measured parameters, theoretical values were used to complete the model. The result is a quite fast (in computer time) and reasonably accurate procedure when used within the designed frequency range of a log-periodic antenna array.

The accuracy of the various antenna subprograms were checked by comparing the computed patterns, where possible, with those published by Ma (Theory and Application of Antenna Arrays, John Wiley and Sons, 1974). The basic differences in the Ma models is the use of 3-term theory for the current distribution, and full complex matrix theory for the solution of the interior problem.

The full IONCAP prediction program has been simplified to two smaller versions. One, MUFLUF version 80.01, is a simpler version which will still perform a full system performance calculation. The other, LIL252 version 81.01, is a smaller version which is for the calculation of field strength only. This program can be used with a newly developed method of evaluating the ionospheric parameters, foF2 and M(3000) factor, which is much simpler and faster than the full Fourier series normally used. A study of the accuracy of the LIL252 method as well as the simplified method of calculating the ionospheric parameters was performed. Various data banks of measured field strength were used. The results are in a report under editorial review for publication.

In the course of using the measured data, it was found necessary to do a study of the relationships between various methods used in the past as well as currently to normalize field strength. This includes definitions of power transmitted, reference fields, and antenna gain. The results of this study in reference to sky-way antenna patterns, ground-wave antenna patterns, and the system loss of a radio circuit have been added to the antenna report.

## SECTION 3.3. DEVELOPMENT AND IMPLEMENTATION OF EM WAVE TRANSMISSION MODELS

Models and Data Base. As part of a continuing effort to determine areas where propagation models and data bases are needed, the Institute has conducted a survey of users of the telecommunications spectrum. This survey was intended to provide information that can be used to decide on which portions of the frequency spectrum further study needs to be conducted. The results of these efforts have been summarized in a National Telecommunications and Information Administration Technical Memorandum [NTIA-TM-81-56] entitled "Present and Future Needs for Propagation Models and Data in Telecommunications". The investigation has shown that propagation models and data bases are needed throughout the spectrum from VLF through EHF. It is necessary that methods be made available to a very diverse user community to simulate the performance of telecommunication systems operating throughout the entire spectrum. Transmission models for those systems that depend upon the atmosphere and the ionosphere are needed. Because of the large potential pay-off in improved spectrum efficiency that will result by operations at high microwave and millimeter wave frequencies, the transmission model studies undertaken with NTIA support tend to emphasize the microwave and millimeter wave portion of the spectrum.

### 3.3.1. Atmospheric Transmission Models

As part of NTIA's effort to study interference fields, descriptions of enhanced fields due to the presence of elevated ducts have been developed at ITS during the last few years. As part of this effort, existing data bases from which to obtain the statistics of many of the duct characteristics must be improved. Improvement can occur both in the area of correcting for the response (or lag), time of duct measuring instrumentation (viz., radiosondes), and in the area of supplementation of these data bases in locations where measurements are lacking (viz., over large bodies of water). To test the effect of these improvements in a given location, radiosonde lag-time corrections were made on five years of data at Washington, DC (1974 through 1978), and some over-water data from the Great Lakes, taken by refractometer, were analyzed.

The following table shows the enhanced occurrence of elevated ducts when an instrument lag-correction procedure is applied to the 5-year Washington, DC, data tape.

Table 3-1 Elevated Duct Total Occurrences and Worst Month Occurrences at Washington, DC

|  | Total | Worst Month (August) |
|---|---|---|
| Total Observations | 3764 | 346 |
| Raw-data Elevated Duct Occurrences | 999 | 156 |
| Lag-corrected Elevated Duct Occurrences | 1280 | 171 |

This table implies a more than 25% increase in elevated duct activity than is indicated by the raw radiosonde data.

Figure 3-16 shows a sample of refractometer data showing an elevated layer at about 1 km height over Lake Ontario on a day when a nearby radiosonde station (Buffalo, NY) did not indicate any layer presence. Unfortunately, there is so little such refractometer data that its overall usefulness in supplementing existing data bases is still uncertain. It is hoped that both the sample-lag correction results and the sample refractometer data supplement will lead to methods whereby the elevated-layer data base for the entire USA can be cost-effectively improved.

VHF/UHF Measurements. The primary objective of this project is to make mobile measurements of the signal strengths and fading characteristics of VHF/UHF broadcasts in an urban area which can be used as a basis for providing improved techniques for predicting the coverage of UHF-TV and mobile radio systems. During FY 80 and FY 81, mobile measurements of the UHF transmissions of Channel 31 (572-578 MHz), and Channel 57 (728-734 MHz) were made and compared with the VHF Channel 9 (186-192 MHz) data. Measurement of these three signals were obtained along the same measurement route [6th Avenue to Valley Highway (I-25) to (I-70)] in the Denver, Colorado, metropolitan area (Figure 3-17). The transmitters are all located in the same general area atop Lookout Mountain with both the Channel 31 and 59 antennas mounted on the Channel 2 tower. Typical samples of the instantaneous signal strengths of these TV transmissions recorded at the intersection of 6th avenue and I-70 (start point for mobile runs) are shown in Figures 3-18 through 3-20.

Statistical analysis of the new UHF multipath data taken in FY 81 has confirmed the earlier conclusions arrived at from the analysis of the FY 80 VHF data. The UHF data also does not always follow a Rayleigh probability density distribution (PDF) and the actual cumulative distribution function (CDF) for mobile reception of UHF can be better characterized by a Weibull exponential probability distribution model. The Weibull model gives the degree of deviation from the Rayleigh random multipath effect. Whenever there are strong specular reflections or the main beam of the transmitting antenna is present, the CDF will deviate from the Rayleigh PDF and becomes an approximation to a Weibull model with a PDF given by

$$p(R;\ \sigma,\ n) = \frac{n}{\sigma}\left(\frac{R}{\sigma}\right)^{n-1} \exp\left[-\left(\frac{R}{\sigma}\right)^{n}\right]$$

where $\sigma$ is the scale parameter, R is the signal envelope, and the Weibull CDF is found directly as

$$P(R;\ \sigma,\ n) = \int_{R}^{\infty} p(R;\ \sigma,\ n)\ dR = \exp\left[-\left(\frac{R}{\sigma}\right)^{n}\right].$$

The exponent, n, can be obtained from the measurements using a straight line approximation to the CDF. When the exponent $n = 2$, the above equation becomes the Rayleigh distribution. Figures 3-21 through 3-23 show the variation of the Weibull distribution exponent obtained for three video signals along the measurement route of Figure 3-17. The Valley Highway (I-25) portion of the path is represented approximately by run numbers 75 through 125. It is apparent that for the Channel 57 video data the distribution is very nearly Rayleigh ($n = 2$) along I-25 and departs markedly from Rayleigh along the 6th avenue and I-70 portions of the measurement route. Figures 3-21 and 3-22 compare the

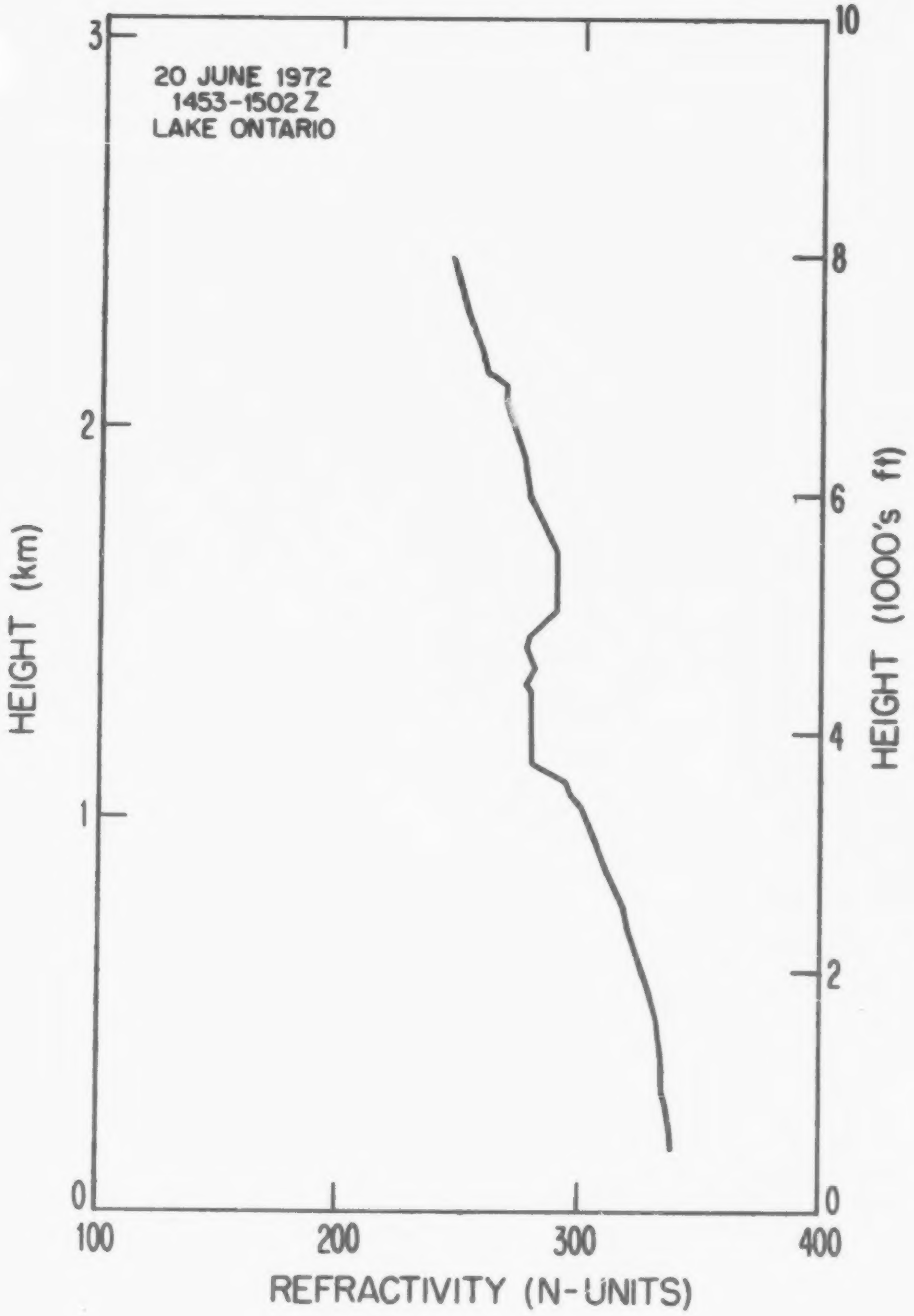

Figure 3-16. A refractivity profile observed using a refractometer over Lake Ontario showing the presence of an elevated layer.

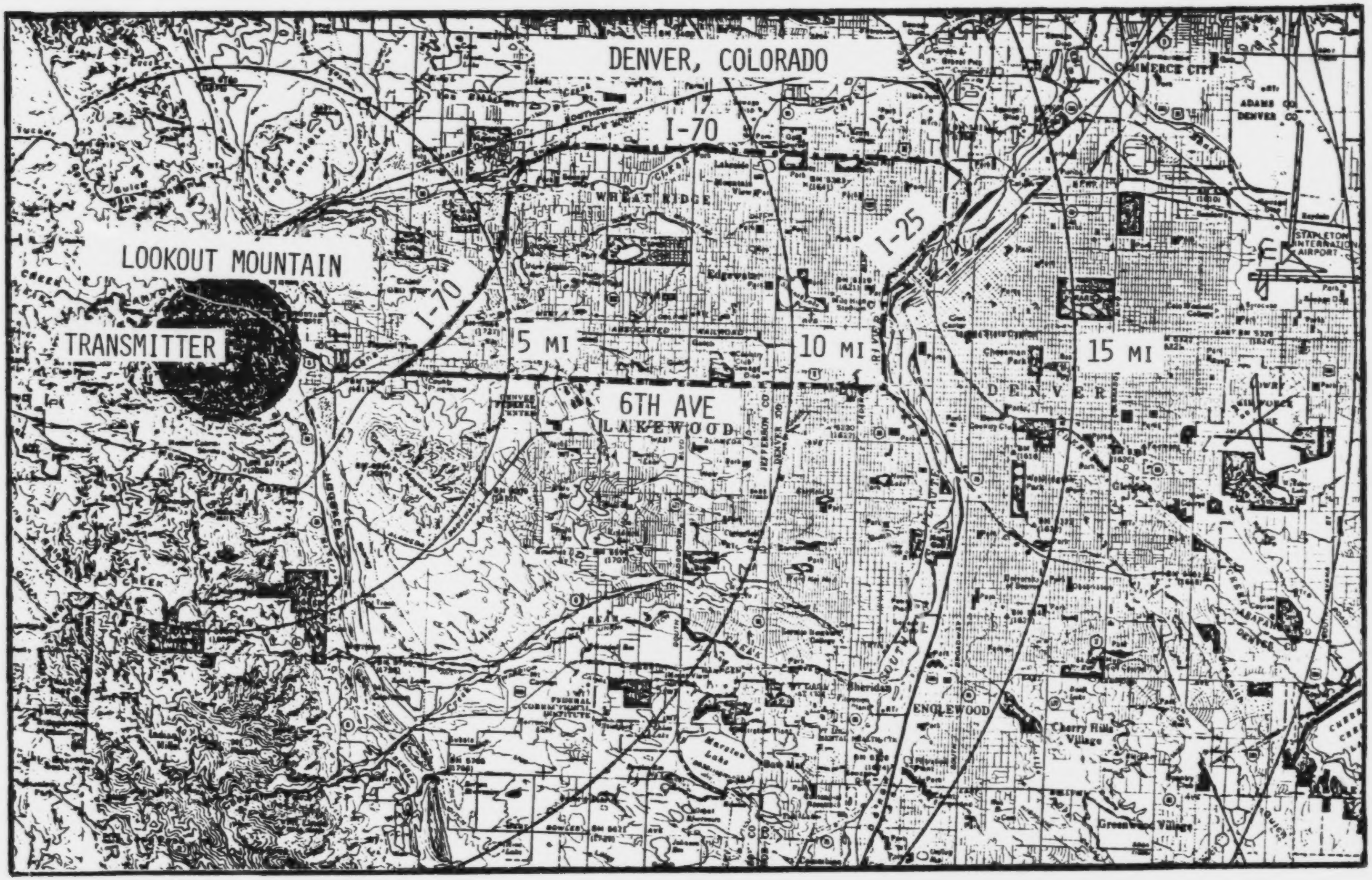
DENVER, COLORADO
I-70
COMMERCE CITY
WHEAT RIDGE
I-25
LOOKOUT MOUNTAIN
I-70
TRANSMITTER
5 MI
10 MI
15 MI
6TH AVE
LAKEWOOD
DENVER
Edgewater
Sheridan
ENGLEWOOD
Cherry Hills Village
Greenwood Village

Figure 3-17. Measurement location area showing Lookout Mountain TV site and route taken by the mobile measurement van.

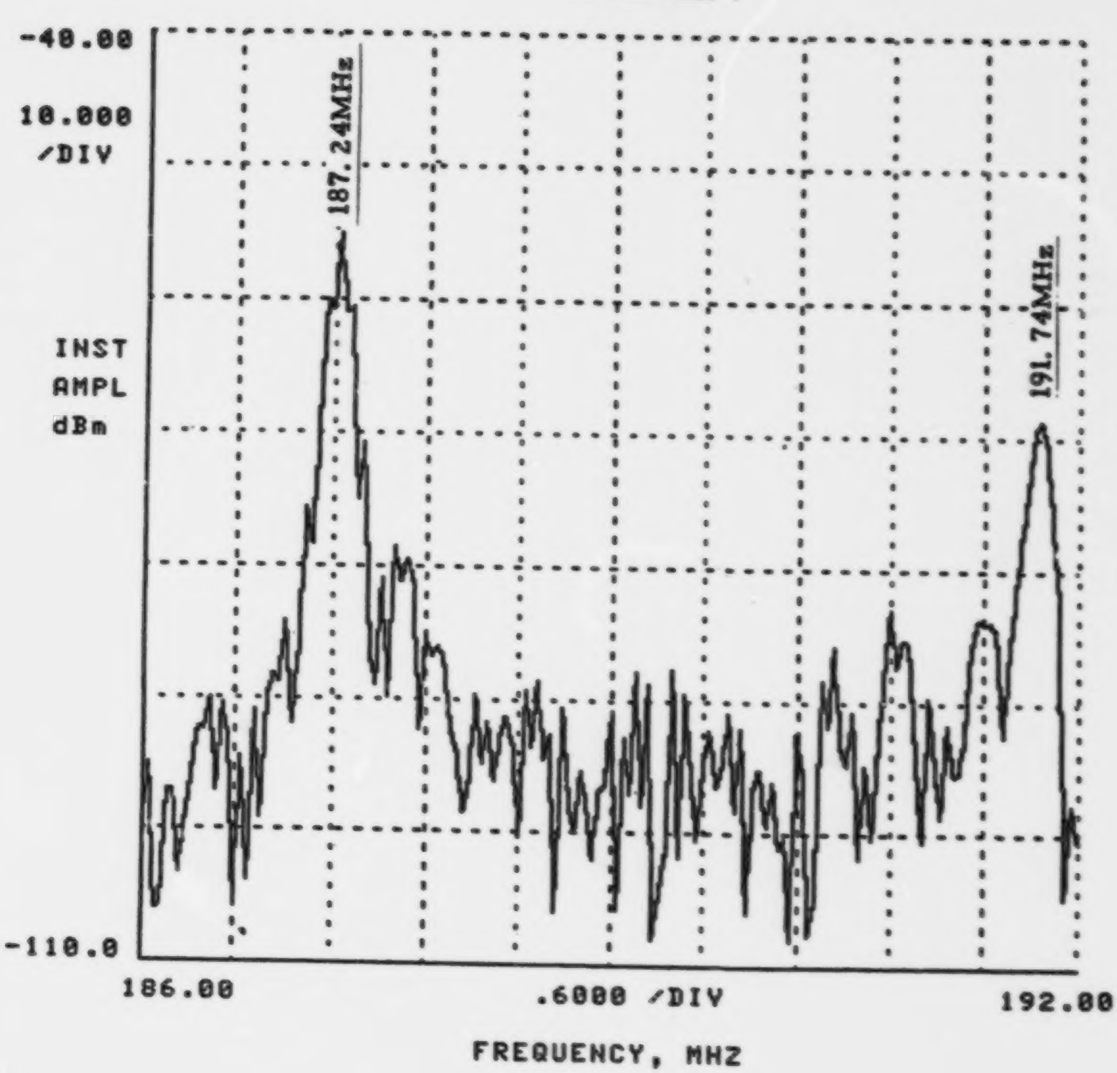

Figure 3-18. Television Channel 9 spectrum measured at intersection of 6th Avenue and I-70.

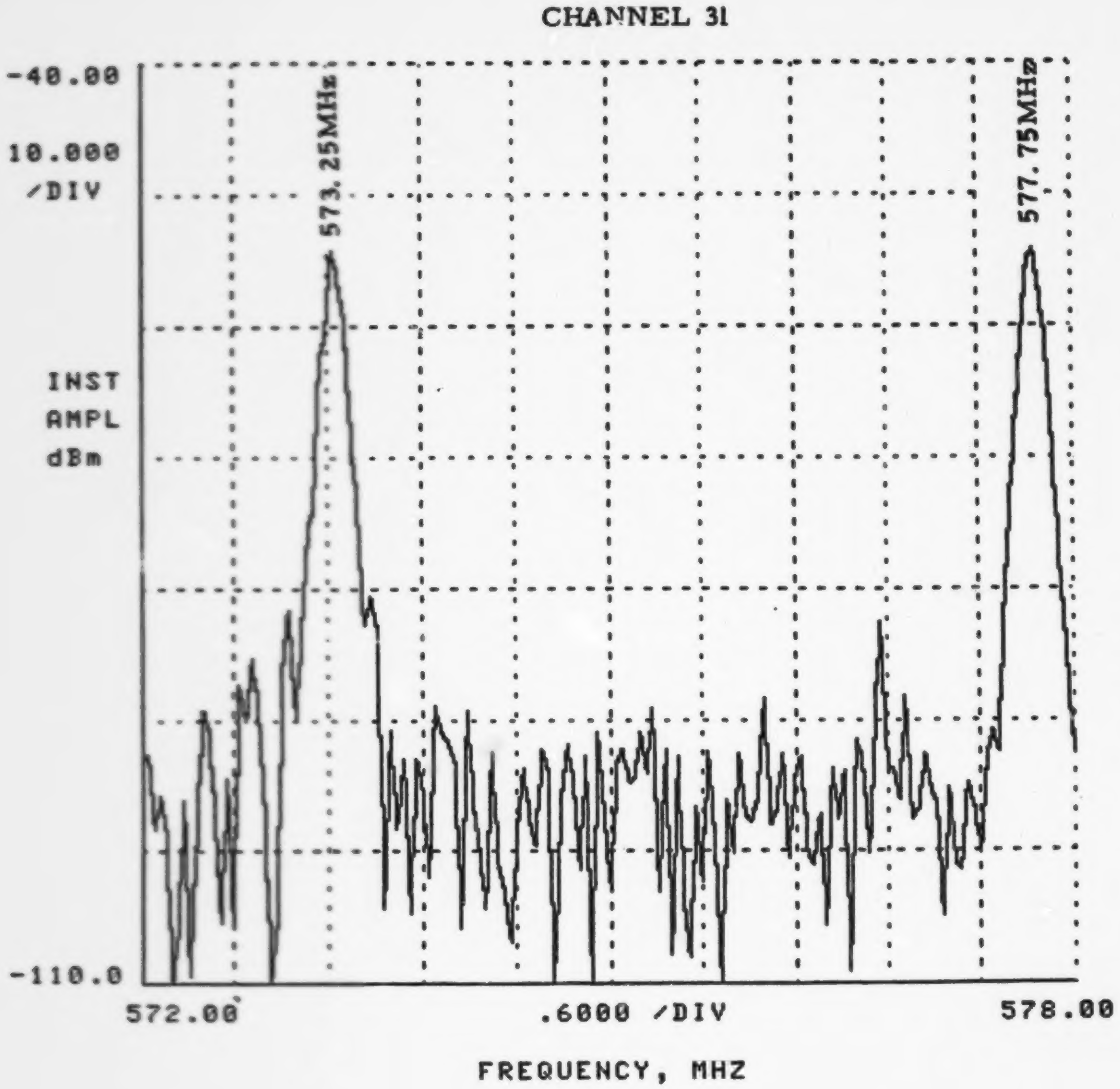

Figure 3-19. Television Channel 31 spectrum measured at intersection of 6th Avenue and I-70.

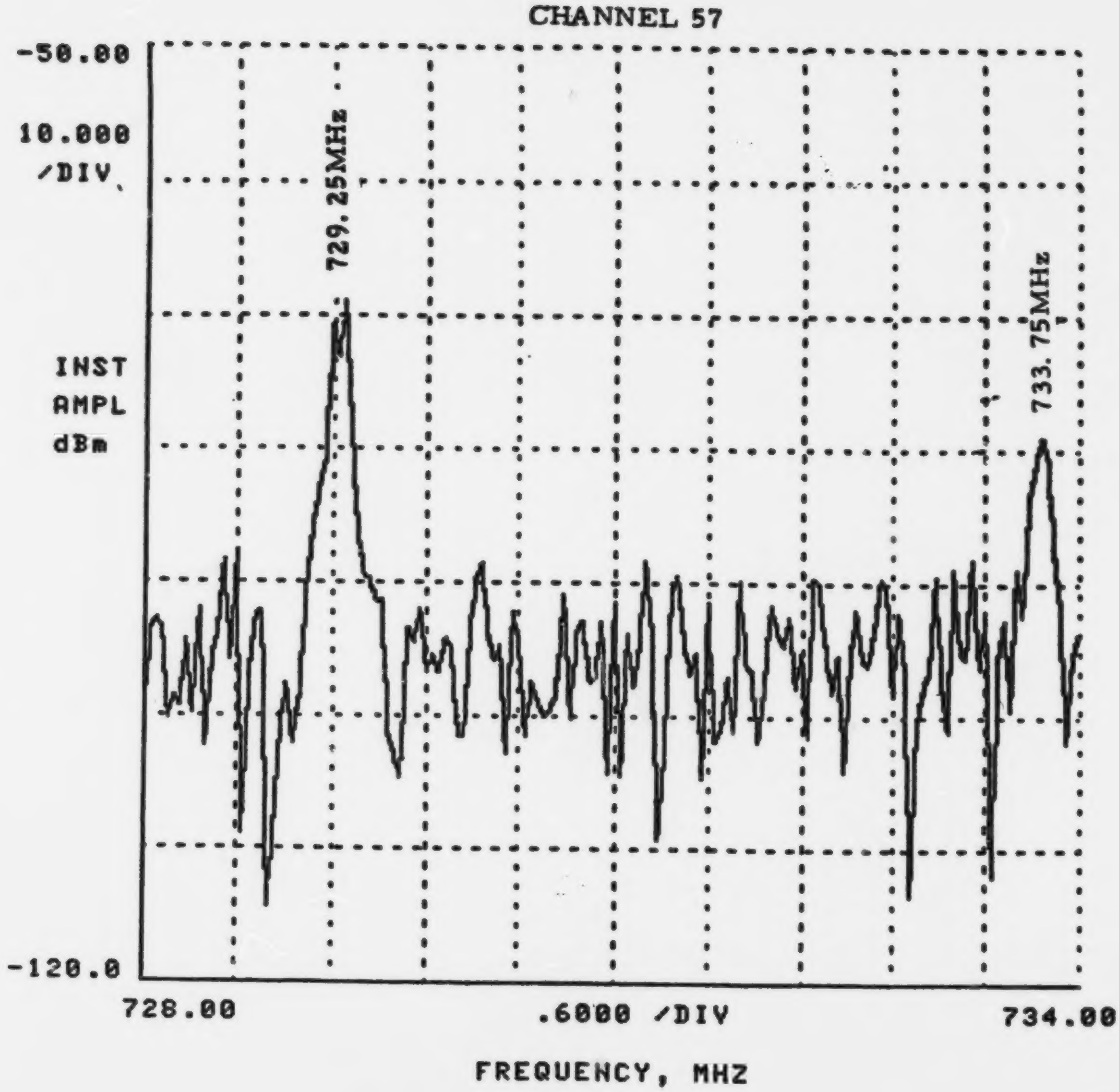

Figure 3-20. Television Channel 57 spectrum measured at intersection of 6th Avenue and I-70.

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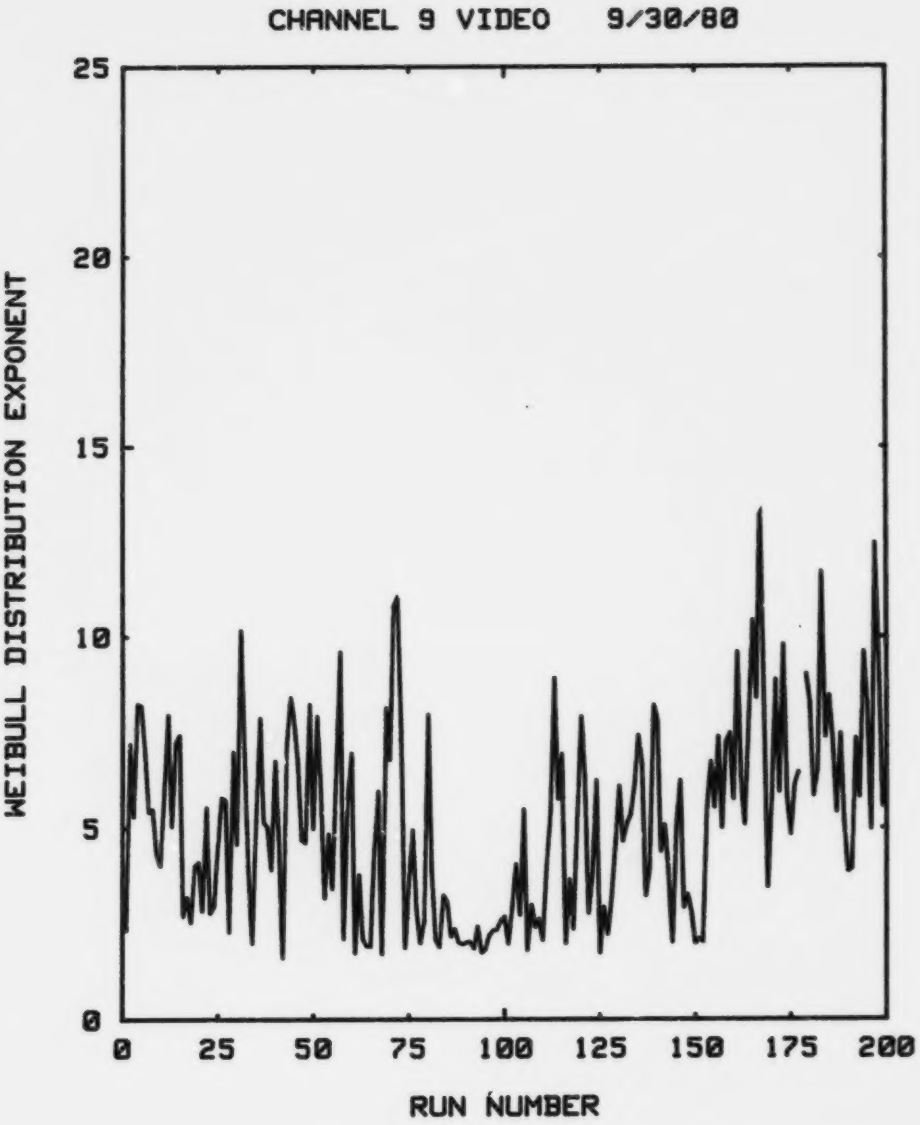

Figure 3-21. The Weibull distribution exponent obtained for the Channel 9 video signal (187.24 MHz) along the measurement route on 30 September 1980.

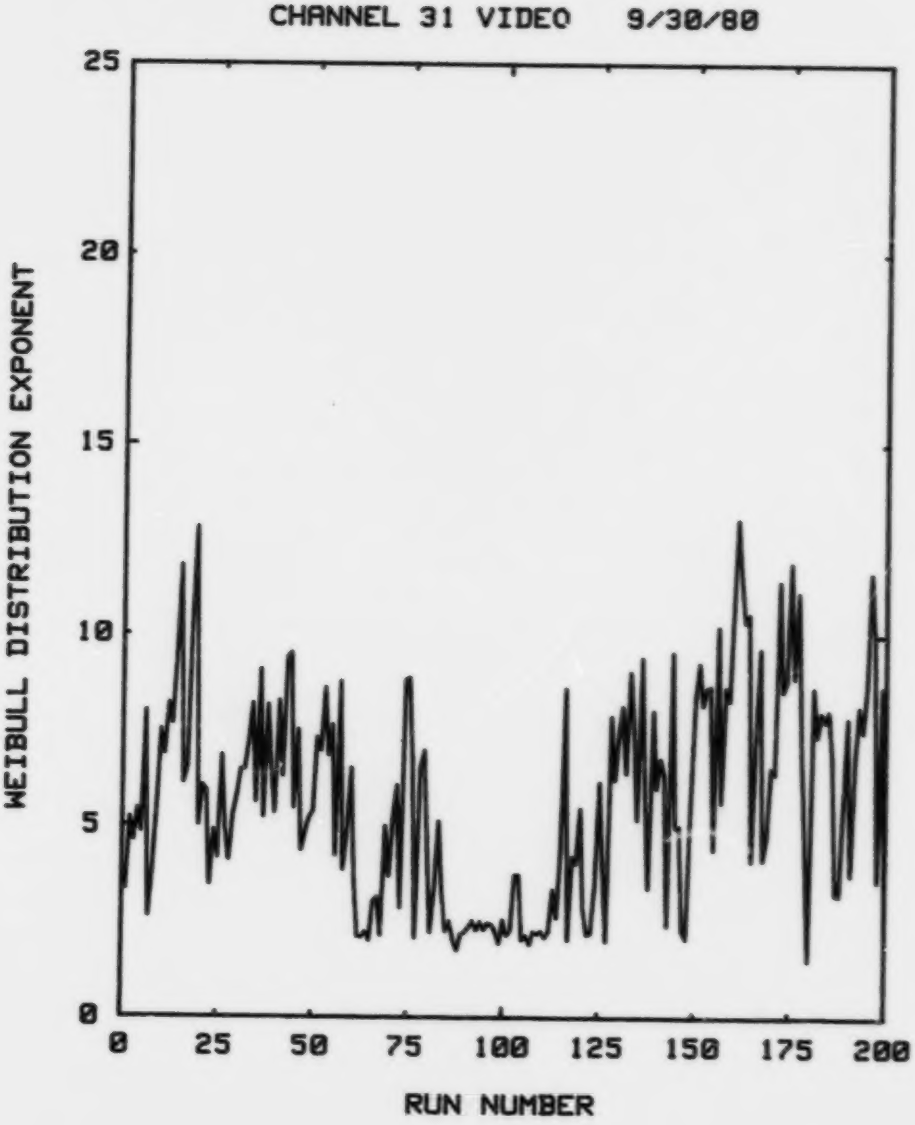

Figure 3-22. The Weibull distribution exponent obtained for the Channel 31 video signal (573.25 MHz) along the measurement route on 30 September 1980.

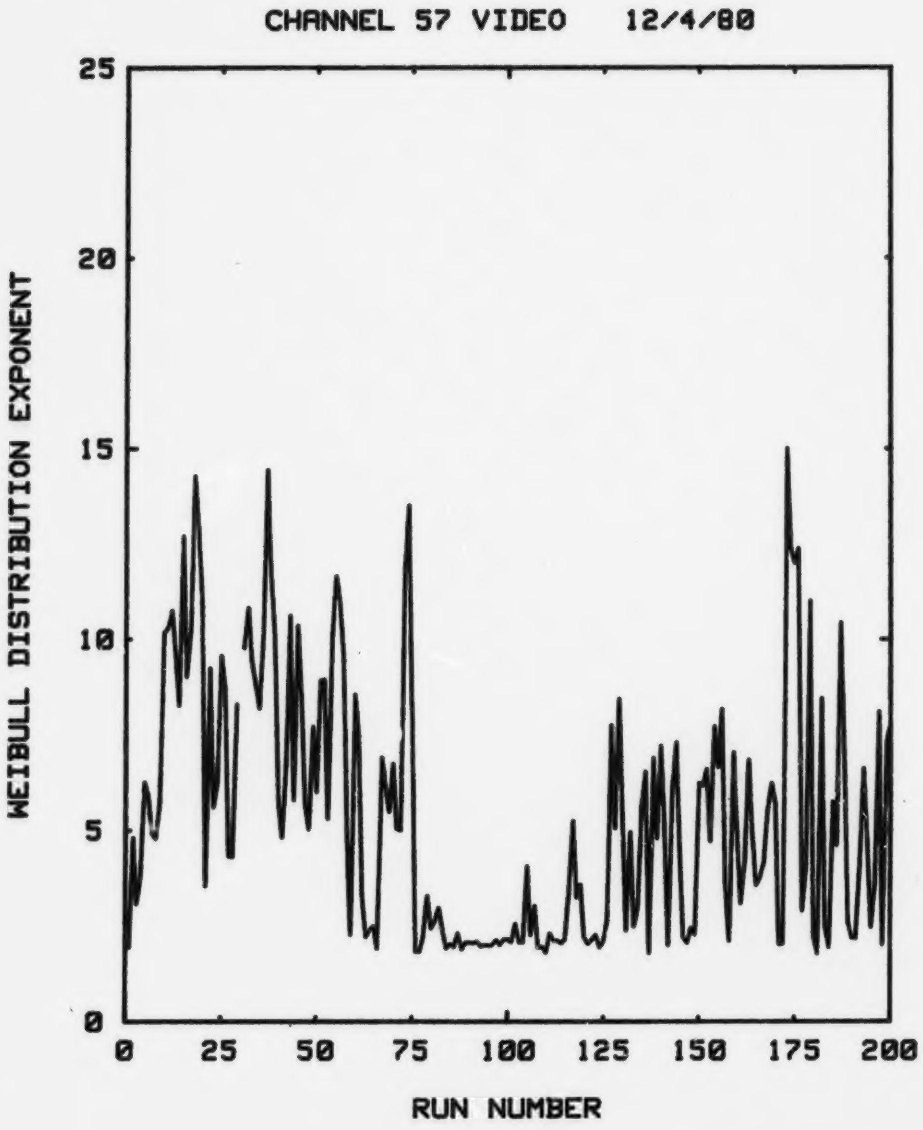

Figure 3-23. The Weibull distribution exponent obtained for the Channel 57 video signal (729.25 MHz) on 4 December 1980.

high degree of variability of the exponent for both a UHF and a VHF signal recorded on the same day along the same measurement route. The physical interpretation of the variation in the Weibull distribution exponent is that the deviation from a Rayleigh distribution gives a measurement of the composite received signal envelope from a random multipath fading characteristic; thus, as the value of n increases above 2 (Rayleigh value), the more the random component of the signal envelope is reduced.

The natural evolution of demand for mobile radio telephone service leads to the ultimate objective of providing it for everyone (that the demand exists is well evidenced by the wide use of CB radio in private vehicles). There are, however, problems in achieving this goal. The most serious problem in mobile communications is the high degree of amplitude and phase fluctuations introduced by the movement of the vehicle. The primary cause of these large signal fluctuations is multipath propagation, and the major objective of this UHF/VHF measurement project has been to measure and study angular multipath at UHF and VHF in the urban environment using a mobile computer-controlled receiver system recently developed by ITS. The early results of these new measurements (in the frequency range of 50 to 800 MHz) have shown that the "local statistics" may not be Rayleigh, and that Weibull distribution may be a better description of the statistical properties of the received field. Much of the mathematical modeling that has been done for microwave mobile communications is based on limited measurements made during 1950-60, which indicated that the envelope of the mobile radio signal is Rayleigh distributed in the frequency range from 50 to 11,200 MHz. The assumption of the Rayleigh model led to results which have been extensively used to study modulation and diversity in the design of mobile communication systems. Whether or not the results of these new measurements will have an impact on the design of mobile communication systems in the future remains to be seen. Also there is the question of the extent to which the data collected in the Denver metropolitan area, and the results of the analysis performed thereon, can be extrapolated to other metropolitan areas. Nevertheless, the results obtained from this measurement program are significant and could affect the mathematical modeling for multipath interference as well as other aspects of mobile communication theory, if they can be shown to be universally applicable for all metropolitan areas.

NASA Propagation Studies. Efforts to describe the distribution of atmospheric attenuation in the presence of rain in the SHF region (3 to 30 GHz) have been an ongoing effort at ITS for several years. A hiatus of a few years in this effort, however, and the development of similar models by other laboratories led to a renewed effort to refurbish the "Dutton-Dougherty" (DD) model, to extend its range of prediction from 0.01% (corresponding to system availability requirements of 99.99%) to 0.001% (corresponding to system availability requirements of 99.999%) of an average year, and to compare it with these other models. The extension of the model for Washington, DC, and comparison with two years' worth of data taken from the Communications Technology Satellite (CTS), operating at 11.7 GHz and at an elevation angle of 29 degrees, is shown in Figure 3-24. The solid center curve of Figure 3-24, marked "1," represents average year attenuation distribution predictions. The two sets of solid curves surrounding the center curve represent 90% and 99% confidence interval predictions of the year-to-year variability in the distribution. The dashed-line curve, marked "2," represents the two years of data from Washington, DC. The relatively good agreement between data and predictions, as well as the improvement over the earlier DD model (to 0.01%) is encouraging, but many more years of data would be required before the validity of the model is really known. In a realistic environment, however, the model will probably have to be accepted or rejected based on limited data. A survey of a number of recently developed dropsize distribution and attenuation coefficient assumptions did not produce predictions apparently as good as that of Figure 3-24 with respect to comparison of predicted and observed distributions at Washington, DC. Two models for the extension to 0.001% have been derived. One of these was based on a heuristic extrapolation of the model's assumption for path rainfall inhomogeneity from the 0.01% level to the 0.001% level. The second model, which was used to obtain Figure 3-24, is based on a more rigorous, theoretical model. Both models, however, gave very comparable predictions in the Washington, DC, 11.7 GHz case.

The goal of Engineering Models (VHF/UHF for Broadcast and Mobile) is to develop, critique, and disseminate useful models of radio propagation. This year's model concerns a generalized context for the treatment of propagation variability and proposes a new way to compute the statistics a designer requires. We have used the term situation to describe where, when, and how equipment is to be deployed; and to the well established time variability and location variability we have added a situation variability. This is the variability observed when one changes from one situation to other "similar" situations. Previously, this third variability has been called "prediction error" and "confidence," terms which we believe are confusing and not entirely descriptive of the process. In addition, we have suggested definite meanings for the terms "confidence" and "reliability" so that we would speak of the confidence with which a proposed new system will enjoy a specified reliability.

### 3.3.2. Ionospheric Transmission Models

Polar Ionospheric Modeling. The polar ionospheric modeling effort is based upon updating an average or, more accurately, a median specification of the polar ionosphere. This median specification follows largely from the numerical coefficients given by the CCIR (CCIR Report 340, 1978) that also form a major part of the HF propagation prediction program given by Barghausen et al. (ESSA Tech. Rept. ERL 110-ITS 78). The polar model contains parameters that characterize the ionization distribution in the various height regions of the

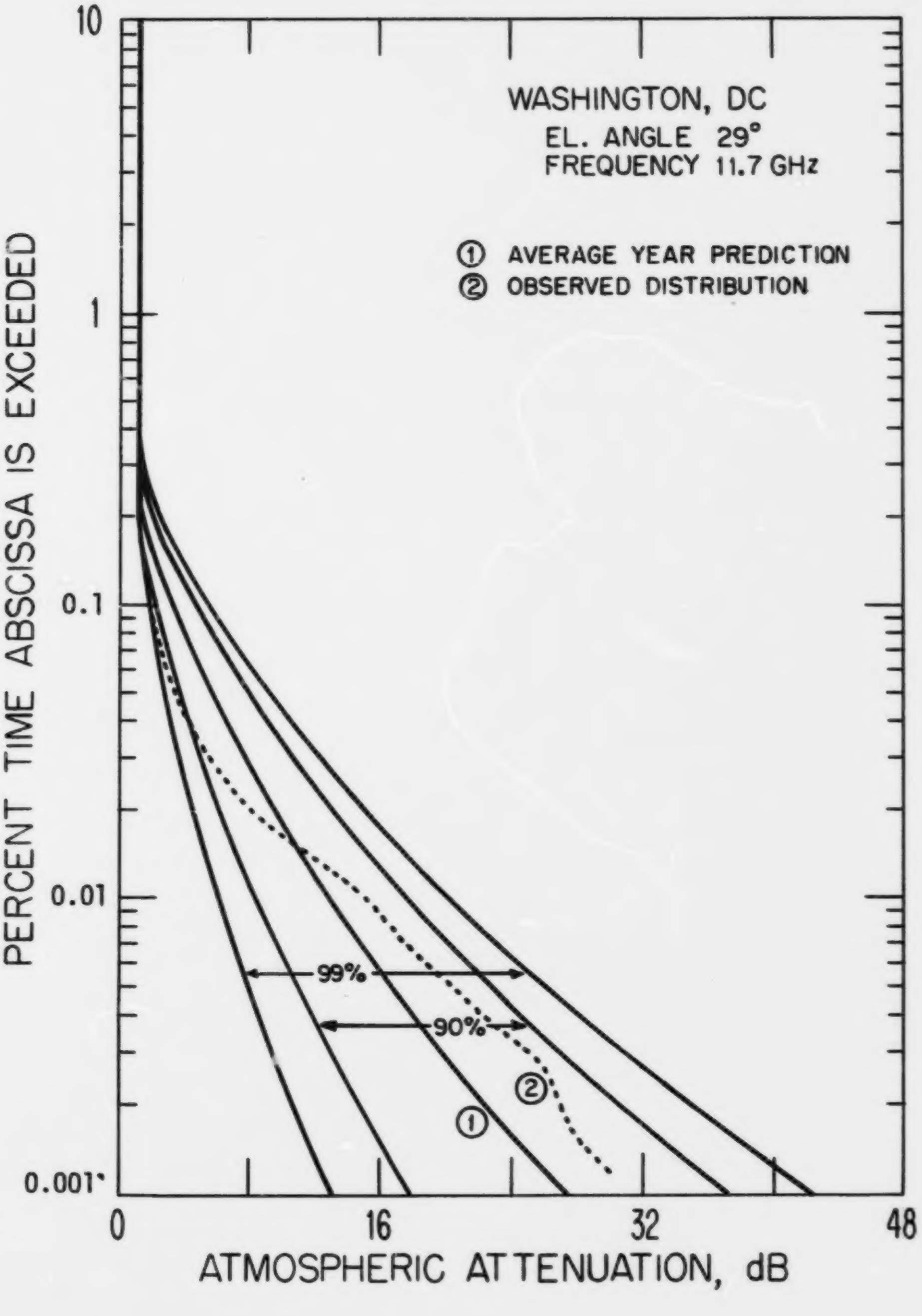

Figure 3-24. Predicted versus observed attenuation distribution using the Dutton-Dougherty model to 0.001%. Curve 1 is the average annual distribution prediction, with other curves predicting 90% and 99% confidence bands of year-to-year distribution variability as indicated. Curve 2 represents two years' worth of data observed from the CT5 satellite.

ionosphere. The parameters are specified in 1.5° degree increments between 12 and 76.5° N latitude and 0.5 to 120.5° W longitude.

The critical frequency of the E region, foE, is determined from the coefficients developed by Leftin (OT Report 76-88). For a given month, median values of foE are generated at any universal time by specifying the Zurich sunspot number.

The height of the E region maximum density is given by a formulation that allows the height to display a smooth transition from day to night conditions. The daytime values of the height of the E region maximum is 110 km and the nighttime value is 120 km.

The semi-thickness of the E region is determined by dividing the height of the E region maximum density by 5.5.

The critical frequency of the F1 region is given by the model of Rosich and Jones (OT Rept. 73-22). Values of foF1 are determined for a limited range of solar zenith angles so as to be in accord with observations.

The height of the F1 maximum density and the semi-thickness is given by

$hmF1 = 165 + .6428\chi$ , $\chi$ is solar zenith angle
$YmF1 = hm/4$.

These parameters are in accord with those given in the IONCAP HF propagation prediction program.

The F2 region critical frequency, foF2, is determined using the coefficients developed by Jones and Obitts (OT Rept. ITS RR3). Values of foF2 are obtained for any month, universal time, and sunspot number.

The height of the F2 region is determined using the relationship developed by Bradley and Dudeney (1973, J. Atmos. Terr. Phys., 35). The semi-thickness of the F2 region is determined by subtracting the value of the F region virtual height from the value of the F2 region maximum height.

Values of foE, foF1, and foF2 scaled from ionograms are used to adjust the median values of the critical frequencies. Simple additions or subtractions to the median data fields are made in order to minimize the difference between monthly median values for a given hour and the observed values for that hour.

There are a number of features in the polar ionosphere that characterize it and distinguish it from other regions of the ionosphere. It is the characterization of these features that form the major efforts undertaken in this effort. Many, if not all of the features of the polar ionosphere can be specified in terms of specific shapes or ovals. The primary shape that is used in this effort is the oval shape that characterizes the statistical occurrence of the visible aurora. The auroral oval as characterized by Feldstein and Starkov (1967, Planet. Space Sci., 15) is used to set the principle features of the polar ionosphere. Specific values of oval activity or Q values are obtained from the World Data Center A.

It is assumed that, during nighttime hours, immediately to the south of the auroral oval there exists a trough of ionization. The northern boundary of the trough is taken to coincide with the southern boundary of the oval. The southern boundary of the trough is set at a variable number of degrees south of the northern boundary. The location of the southern boundary and the depth of the trough can be varied so that the values of foFe in the trough and the latitudinal extent of the trough can be made to agree with available observations.

The model of the auroral E region follows closely the work of Gassman (1973 AFCRL Tech. Rpt. TR-73-0151). The critical frequency of the auroral E region is determined in terms of a maximum value of the critical frequency foEa max according to the Q index. The Q index not only specifies the maximum value of foEa, it also specifies the location of the boundaries of the auroral E region. Observations of foEa obtained from vertical incidence sounding data can be used to corroborate the values of, and locations of, foEa determined from the model. Since the model of foEa is specified in terms of Q only, any large differences between model and observation can be minimized by using a value of Q in the model that yields results agreeing with observation. In other words, the value of Q can be adjusted in order that the foEa model yields results that agree with observation. In the absence of any vertical incidence data, the value of Q provided by the World Data Center A drives the auroral E region model.

A given value of Q specified the location of the auroral E region which is tied to the location of the auroral oval. The location of the auroral oval is determined in corrected geomagnetic coordinates which are converted to the appropriate geographic coordinates in order to effect the calculations.

The formulation for the auroral E region is given as follows:

1. foEa max

$$\begin{aligned} foEa\ max &= 2.5 + \frac{Q}{9} & 0<Q\leq 2.7 \\ &= \frac{7}{5}Q - 1 & 2.7<Q\leq 4.2 \\ &= 5 & Q > 4.2. \end{aligned}$$

2. foEa at any point, $\phi_A$ greater than $\phi_m$

$$foEa = foEa\ max - \frac{.4\ foE\ max}{[\phi_N - \phi_m]} \cdot [\phi_A - \phi_m].$$

3. Latitude of northern boundary $\phi_N$, is equal to one half the difference between the northern and southern boundary of the oval plus the southern oval boundary.

4. Latitude of southern boundary $\phi_s$ is equal to the southern boundary of the oval.

5. Latitude of foEa max

$$\begin{aligned} \phi_m &= \phi_s & Q \geq 3.0 \\ &= \phi_s + 1 & Q < 3.0 \end{aligned}$$

a. If $\phi_m = \phi_s$ $(Q \geq 3.0)$, there are no values of foEa to the south of $\phi_m$. If $\phi_m = \phi_s + 1$, the value of foEa one degree south of $\phi_m$ is taken as 0.6 foE max.

6. hmEa max

$$\text{hmEa max} = 185 - [\text{foEa max} - 2] \times 35, \quad 2.5 < \text{foEa max} \leq 3.5$$

$$= 145 - [\text{foEa max} - 3] \times 10 \quad \text{foEa max} > 3.5.$$

7. hmEa at any point $\phi_A$ greater than $\phi_m$

$$\text{hmEa} = \text{hmEa max} + \frac{10[\phi_A - \phi_m]}{[\phi_N - \phi_m]}$$

a. When $Q<3.0$, there is a value of foEa occurring to the south of foEa max. At that point (equal in latitude to $\phi_s$), the value of hmEa is set equal to hmEa max + 10.

8. ymEa = hmEa/3.

The absorption model developed by Foppiano (CCIR Supplement to Report 252-2, 1978) has been incorporated into the computer code and is used as the basis of the auroral absorption model.

The absorption model developed by George and Bradley (1974, ITU Telecomm. J., 41) is used as the basis for the normal absorption of HF radio waves.

The E region irregularity model developed by Gassman (1973, AFCRL Tech. Rept. TR-73-0151) forms the basis of the initial E region irregularity model.

A program of polar ionospheric modeling support has been undertaken. The effort centers around updating median models of the polar ionosphere with actual observations. The parameters that characterize the polar ionosphere are:

foE
hmE
YmE
foF1
hmF1
YmF1
foF2
hmF2
YmF2
E region irregularity indicator
F region irregularity indicator
Northern auroral oval boundary
Southern auroral oval boundary
Northern trough boundary
Southern trough boundary.

Prediction techniques for area coverage of HF Communication Systems. It is often useful to have ionosperic propagation predictions presented in a form to assist in the estimation of geographic coverage of a given frequency at a given time and with a specific antenna. Predictions such as the MUF, circuit reliability, signal-to-noise ratio, and median field strength could aid HF broadcasters and others if presented in a geographic latitude-longitude matrix display for specified areas of the world. The modeling effort reported here is the result of a task to develop such a geographic latitude-longitude display of ionospheric propagation predictions.

The task consists of development of a procedure to generate a geographic area coverage representation of ionospheric characteristics given a specific area. The area is identified by either a code which targets a predefined geographic area or by specification of the latitude and longitude boundaries of the area. The ionsopheric propagation predictions are computed at the boundary locations of the grid and at incremental locations within the grid. The area coverage representation consists of the display of these predictions on a matrix grid for each frequency and each hour for a specified month and antenna. The area coverage representation, therefore, consists of the predictions of several point-to-point communication paths on a rectangular grid.

The implementation allows the flexibility to identify the construction of rectangular grids where: (1) a specific transmitter location is used to communicate with each receiver location on the grid, (2) each location on the grid is considered a transmitter and is used to communicate with a specific receiver location.

The Ionosperic Communications Analysis and Prediction Program (IONCAP) is used to compute the ionospheric propagation predictions for this effort. The procedure consists of development of a processor to generate the input to the IONCAP program based on the specific grid to be constructed and a processor to generate the geographic grid from the IONCAP predictions. There are distinct advantages to this procedure. The IONCAP program is a point-to-point communications program and does not directly construct area coverage grids. The input processor generates the geographical area as a set of point-to-point communication paths that IONCAP can use without major modification to the IONCAP program. The IONCAP program is utilized more effectively by evaluating a particular point-to-point path at all specified hours and frequencies rather than all point-to-point paths at a single hour and frequency. It is also more efficient to compute all desired propagation predictions (i.e. Maximum Usable Frequency, (MUF), field-strength and signal-to-noise ratio) for a particular path rather than the prediction of each parameter for all paths. That is to say, the IONCAP program does not compute the predictions in the same order as is needed by the geographical area coverage model. The output processor, therefore, reads the IONCAP predictions and generates the desired area coverage grid.

The U. S. Army Communications Research and Development Command (CORADCOM) is concerned with estimating channel characteristics for the design of ground-to-ground mobile spread-spectrum communication systems. Potential deployments include varied terrain and foliage.

In support of this concern, the Wideband Measurements project has acquired a set of data and is presently developing techniques to analyze them. The data were measured during October 1979 in south central Tennessee where a forest management program provided an excellent test environment. The measurements obtained were a digitization of a direct representation of the impulse response function derived from a pseudo-noise channel probe with a 300 MHz bandwidth. The center frequencies were at 600, 1200, and 1800 MHz.

In Figure 3-25 we have reproduced a single recorded impulse response. The propagation path began with a transmitting antenna buried in the forest and ended at a receiving antenna on a tower about 8 m above the forest top and about 160 m away. The figure shows both the co-phase and quadrature phase components and has been normalized so that (1) the onset of the function is at a fixed point and a long noise record in the tail has been deleted, and (2) the total apparent energy of the response has been fixed. If one measures from the time when 5% of the response energy has been recorded to the time when 95% has been recorded one finds a delay spread of 180.4 ns. Similar values were obtained on other forest penetration paths.

Figure 3-26 is the spectral response function corresponding to the impulse response function of Figure 3-25. It has been normalized by subtracting out the effective pulse of the pseudo noise probe. We seem to have measured frequency selective fading over a band that is about 200 MHz wide, and we have done that in a fraction of a second.

The Use of Theoretical Models to Improve Global Maps of foF2. Maps of monthly median ionospheric parameters valid for the entire globe form the basis for a number of empirical and statistical models of the ionospheric electron density. The accuracy of such models is therefore tied directly to the accuracy of the maps of the ionospheric parameters. Maps of the critical frequency of the E region, foE, the critical frequency of the F1 region, foF1, and the critical frequency of the F2 region, foF2 have been employed in one form or another to determine ionospheric structure, HF propagation conditions, and transionospheric propagation factors. Studies have been reported describing how the global maps of monthly median ionospheric parameters can be modified with daily ionospheric observations in order to more realistically represent the daily variations in ionospheric structure.

The global maps of ionospheric parameters are generated from numerical coefficients obtained by performing a spherical harmonic analysis on observed monthly median values of foE, FoF1, and FoF2. The resultant accuracy of the maps is dependent upon the geographical distribution of the data that were used in the generation of the coefficients. The data, foE, foEl, and for foF2, that were used in developing the global maps were obtained from between 100 and 150 vertical incidence ionosonde stations that operated throughout the world. These stations provided observations that permit a reasonably accurate map of the ionospheric parameters at these locations for which data were available. At locations for which data were non-existent, such as for ocean areas, the accuracy of the maps is questionable.

It has long been appreciated that the uncertainties in the maps of foF2 are the largest source of potential error in any ionospheric model that utilizes global maps of median ionospheric parameters. This is due principally to the fact that the F2 region is the most variable of the ionospheric regions displaying large changes on both temporal and spatial scales. The variations in the F2 region are the manifestation of complex interactions between neutral and ionized constituents at ionospheric heights, the dependence of F2 region phenomena upon the geomagnetic field, and the influence of the magnetosphere on the ionosphere. The variability of the F2 region renders it difficult to extrapolate observations of foF2 at one location to another location with a degree of accuracy that is commensurate with extrapolation procedures employed for the E and F1 regions. In order to rectify this situation somewhat, it was decided to employ a theoretical model of the ionosphere to generate values of the F2 region critical frequency in low and mid-latitude parts of the world where observations of foF2 are unavailable. The values of FoF2 determined from the theoretical model were then combined with actual observations of foF2 and, in some instances, with values of foF2 determined from the existing sets of coefficients. These data then formed the basis for re-generating the numerical coefficients that yield global maps of the F2 region critical frequency for specific months. The resultant maps provide a means to specify foF2 on a global basis that is consistent with observation and with the physical understanding about the structures of the low and mid-latitude F2 region and the causes of its large-scale variations.

Wideband Radio Over-the-Horizon Link Design. In order to improve the efficiency of designing beyond-the-horizon radio links, ITS will provide an automated, interactive set of desk-top-computer programs which will permit workers with moderate skill levels to perform the calculations necessary for the design of beyond-the-horizon microwave links for both FM/FDM and PCM/TDM systems. The programs are to be provided with documentation which will permit them to be easily operated, understood, modified, and updated.

The models used will cover over-the-horizon links operating between 40 MHz and 10 GHz. The models will not cover any of the ionospheric modes which occasionally are operative at the lower end of this frequency range. The programs will not cover mixed modes of radio propagation such as are observed in cases where diffraction and tropospheric scatter modes occur alternately or at the same time. The project is sponsored by USA CEEIA.

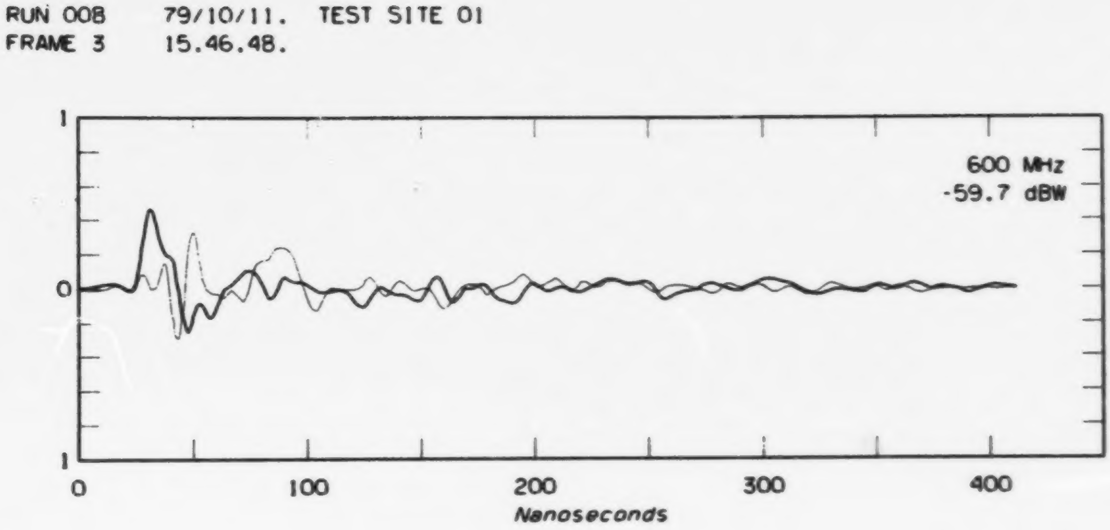

Figure 3-25. The co-phase and quadrature phase components of an impulse response after the wave has traveled into a forest.

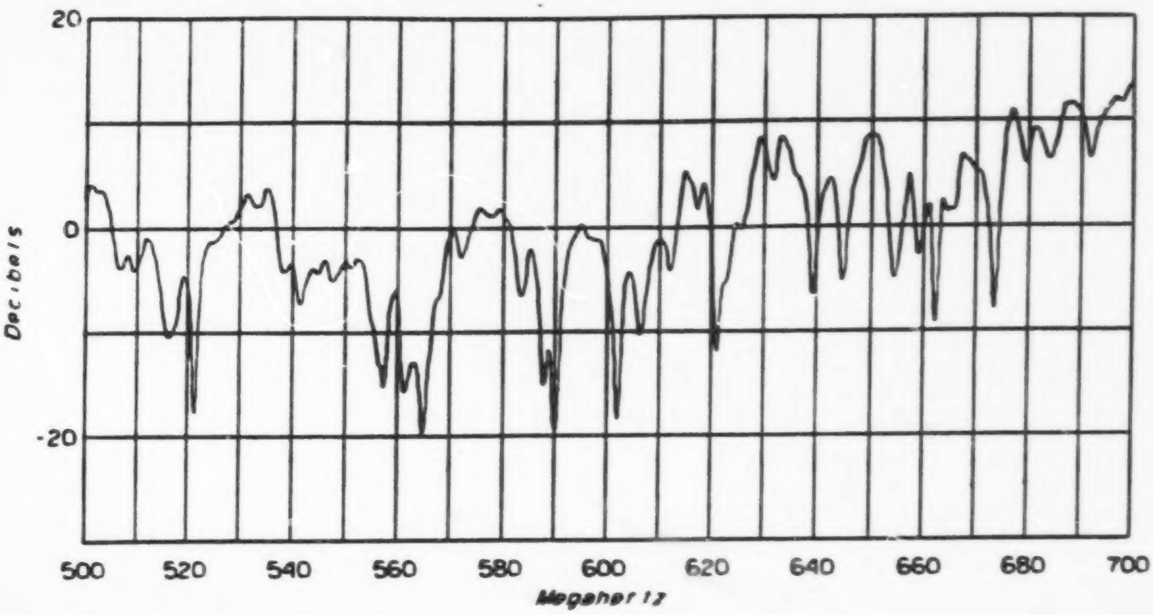

Figure 3-26. The spectral response corresponding to the above impulse response.

## SECTION 3.4. PREDICTION OF TRANSMISSION PARAMETERS AND SYSTEM PERFORMANCE

Completed engineering models for EM wave transmission calculations are delivered to sponsoring and requesting agencies for their use. Following are representative uses of these services.

### 3.4.1. Long-Term Ionospheric Predictions

Propagation Predictions for the WARC on HF Broadcasting. The World Administrative Radio Conference (WARC), Geneva 1979, requested the CCIR "to adapt the present method of propagation predictions in order to make it more suitable for use in planning broadcasting." Study Group 6 of the CCIR has set up an Interim Working Party (IWP) 6/12 in response to this request. The U.S. has accepted the chairmanship of this IWP with following objectives:

(1) to study the requirements for propagation prediction methods for use at the HF Broadcasting Planning Conference;

(2) to consider the available methods of propagation prediction at HF, and to consider relevant information now being studied by Interim Working Party 6/1 and Interim Working Party 6/3 which are suitable for planning purposes;

(3) to propose and evaluate the most suitable propagation prediction method for use at the planning conference; and

(4) to recommend the most suitable values of solar activity index for use with the proposed prediction method.

Under U.S. chairmanship (Donald L. Lucas), the IWP has conducted three meetings--Estes Park, Colorado, January 19-21, 1981; Darmstadt, Germany, May 18-20, 1981; and Geneva, Switzerland, August 20-21, 1981. Thirty-three Administrations and operating organizations are participating in the work of IWP 6/12, and more than 20 have attended the meetings. The ITS effort has been in the preparation of material for consideration at the meetings, conducting the meetings, the investigation of contributions between meetings, and the preparation of a report for consideration by Study Group 6. In response to the objectives, the following decisions have been reached:

(1) Requirements for prediction methods: The basic requirement is for a fast field-strength prediction method. The prediction of the monthly median of hourly median field strengths is essential. The accurate prediction of nighttime fields requires special consideration; and the prediction of Maximum Usable Frequencies, either as part of the field-strength prediction method or as a part of cull procedures, is necessary.

(2) Available Methods: Most Administrations have skywave propagation prediction methods, either unique or some adaptation of the methods of other Administrations. Methods of international acceptance (CCIR) are those of CCIR Report 252-2 and Sup. 252-2. Another method of established usage is that of the Federal Republic of Germany.

(3) Most Suitable Method for the Planning Conference: Considerable effort was devoted by ITS to adapt the CCIR 252-2 method to assure rapid, efficient use on computers. IWP 6/12 has accepted this effort for circuits out to 7000 km and has recommended the use of the highly empirical FTZ method at the greater distances.

(4) Solar Activity Index: Values of 12-month, moving average Zurich sunspot number are recommended as a suitable solar activity index. The actual values are dependent upon the number of solar activity epochs used in planning the use of the high frequency bands allocated to the broadcast service.

The Voice of America requires regular predictions of "circuit" performance as an aid in planning appropriately for the continuation of its worldwide HF broadcasts.

The Radio Propagation Predictions project provides the VOA every second month with HF circuit performance predictions for about 180 broadcast circuits eight months in advance. For about 150 of these circuits (from Tinang, Kavala, Greenville, Wooferton, Monrovia, Munich, and Tangier), the predictions include selection of optimum transmitting antenna.

Computer files have been maintained for local batch processing and for use by VOA from a remote terminal. Interactive preparation of data for the prediction programs is possible.

During fiscal 1981, HF radio propagation predictions were provided routinely to ITT World Communications, the American Radio Relay League (for publication in QST), TRT Telecommunications Corp., and NOAA (SEL). Predictions were also made for Crawford International (to be a monthly subscriber in FY 1982); Canadian Marconi; BR Communications; Dr. W. A. Kissick of ITS; Page Communications; Sanders Associates; Magnavox; General Dynamics; Smith Electronics; Morrison-Knudsen; Hughes Aircraft.

VOA HF Propagation Studies. The Institute has provided support to the Voice of America [VOA] in the areas of HF propagation predictions and operational studies for a number of years. This support has continued through this year. The Institute has provided circuit performance predictions for over 180 VOA broadcast circuits. These predictions are used by the Voice of America in the scheduling of frequencies for broadcasts. In addition the Institute has provided VOA with a remote access to its computer programs that are used to determine HF propagation conditions.

Specific studies have been undertaken by the Institute in support of Voice of America preparation for the 1984 HF Broadcasting WARC. A study to determine the optimum duration of a broadcast schedule has shown that the current scheduling practices of the VOA - changing frequencies four times a year - are about ideal. A study has also been undertaken to determine the power needed by a broadcast transmitter to provide a signal level of 60 dBu to a specified distance away from the transmitter. The results of this study have been contained in a document prepared by the Voice of America and submitted to the CCIR for its Study Group 10 meeting. Figure 3-27 provides a summary of the results of this study. Shown on the figure is the power necessary to provide a 60 dBu as a function of distance from a 1 kW transmitter for at least 50% of the time (which is typical of a nighttime operation) and for 90% of the time. These results are being used by the Voice of America to assist in determining their position on the transmitter power that is necessary in order to provide good listener quality service.

The Ionospheric Communications Analysis Prediction Program (IONCAP) is the most recent of the HF prediction programs developed at the Institute for Telecommunication Sciences (ITS). The computer program is an integrated system of subroutines designed to predict high-frequency (HF) sky-wave system performance and analyze ionospheric parameters. These computer-aided predictions may be used in the planning and operation of high-frequency communication systems using skywaves.

In the initial planning or in the modification of many communication systems there may be an appreciable delay between the circuit planning and the actual circuit construction or modification. This is of particular importance for high-frequency (HF) circuits which have marked time and geographic variations in optimum frequency, required power, and system performance.

Predictions of ionospheric characteristics and techniques for using these characteristics are available and may be used to anticipate the performance of HF communication circuits and thereby provide the lead time for necessary equipment selection, frequency selection, and frequency and time-sharing arrangements.

Specific modeling efforts included in the IONCAP program are:

1. A complete explicit electron density profile. While this function is not measurable, the integration of the profile to give an ionogram is. These prediction ionograms have been checked against measurements.
2. For oblique ray paths, Martyn's theorem has been corrected for a curved ionosphere. The correction was derived to assure agreement with full ray tracing using the same electron density profile.
3. Explicit sporadic E modes have been added to the program. The model is composed of subparts which have been derived from and tested against measurements over the past 30 years.
4. A revised median loss model has been created. The same basic equation is used, but an additional term is added for E modes, and a revision of the collision frequency term for modes with reflection heights within the absorbing region added. Also, a deviative loss term is added to high angle modes (these are also an addition to the program). The revision as well as the total loss equation was compared to field strength measurements.
5. An MUF model has been added which directly calculates the values rather than searching for the correct value. The complete electron density profile is used. The distribution of the MUF over a specified month for each possible layer is now included.
6. The distribution of transmission loss has been extended to vary with each operating frequency and with each type of mode. This allows the extension of statistical system performance upward in frequency.
7. Some modifications to the antenna models have been made, the most significant being for vertical antennas which are electrically short.
8. The complete set of models for long paths, as described above, have been added.

   A major effort is currently in progress to replace all of the antenna models used in the IONCAP program.

The IONCAP program or calculations using the program are available from the Propagation Predictions and Model Development Group of the Applied Electromagnetic Science Division of ITS. The program has been supplied to several foreign and domestic government agencies and to the private sector.

Ground-Air Propagation. The Institute has developed numerous HF propagation prediction codes over the years. For the most part these codes have been somewhat complex in keeping with the complex nature of the propagation medium itself. Recently an effort was initiated to develop a rapid method to simulate the performance of

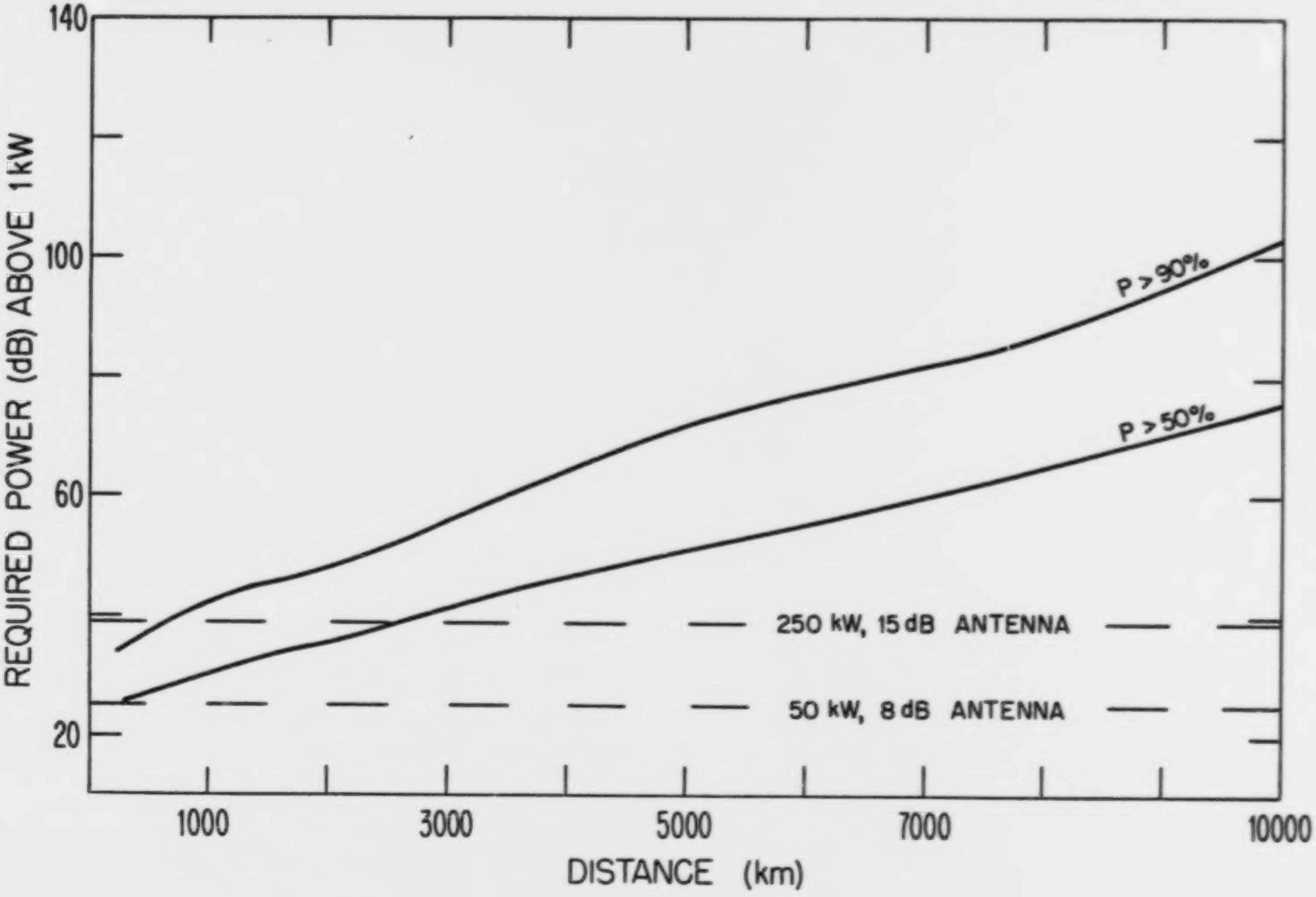

Figure 3-27. Required power for 60 dBu; all circuits, P>50%, P>90%.

ground-to-ground and ground-to-air HF systems. The objective of the study is to provide a computer code that can be used as part of more sophisticated codes to undertake system design studies and operational trade-off analyses.

### 3.4.2. Medium Frequency Transmission Studies

**MF Sky-wave Propagation.** The higher powered AM Stations south of the U.S. border have caused interference to some U.S. AM broadcast stations. Current accepted prediction models tend to underestimate field strengths in the Western Hemisphere. To remedy this the Institute in cooperation with the Federal Communications Commission established an MF sky-wave monitoring field site at Cabo Roja, Puerto Rico to actually observe signals from the more southerly South American stations. This capability provides data with sky-wave reflection points below 30° north geomagnetic latitude which, in the long term, will yield information so that the effects of frequency, geomagnetic latitude, ionospheric loss, and solar activity on the performance of long distance MF signals can be properly evaluated. This in turn would lead to a realistic MF sky-wave prediction model.

At the Puerto Rican site sky-wave signals were observed from several South American AM stations on highly directional antennas. In some cases single stations were audible on given channels. Those identified appear in Table 3-2. In addition, frequencies on which there were known high powered stations from Europe and Africa were monitored. Carriers were observed on several European channels but no heterodynes were observed when tuned to local broadcasts.

**FCC MF Measurements.** In support of a program of analysis designed to provide quantitative predictions of trans-equatorial interference from South American MF broadcast stations, equipment was designed and developed with which actual signals from representative stations could be recorded. This fully automatic equipment has been in operation in Puerto Rico since spring of 1981, and is expected to be maintained for approximately one year. Signal strength data for several identified stations in South America are recorded on digital tape. Periodic audio recordings are also made to provide a continuing confirmation of each station by call sign and to provide assurance that signal strength from records are for clear channel reception, i.e., from a single station whose location and operating parameters are unambiguous.

The Puerto Rican siting was selected to provide a southerly (Northern Hemisphere) location to avoid signals of marginal strength. The automatic receiving and recording equipment was first situated at the Roosevelt Roads Naval Station in eastern Puerto Rico as a convenient government site, adequately protected and with available base services for changing and mailing the data tapes. Since no directional antenna was available -- nor could be provided within the scope of the project -- a loop antenna was used. The data thus acquired suffered from some ambiguity, both in clear identification of the broadcast stations received and in the reception of more than one station on one frequency. A resolution to these difficulties was accomplished with the discovery of (and subsequent redeployment to) an existing farm of Beverage directional antennas located at the National Wild Life Refuge in the Cabo Roja Sector of southwestern Puerto Rico.

Additional equipment elements were designed and constructed with which the automatic recording receiver could be matched to and switched among the Beverage elements. These antennas had been installed by another government agency at an earlier date and later abandoned. In setting up at the Cabo Roja site, four of seven 1,800 foot long Beverage antennas were determined to be in servicable condition for use as receiving antennas. These were checked, repaired, and connected to the automatic receiving and data recording system.

Trial operational tests were conducted to check out the entire system and to select candidate stations for routine monitoring. The Beverage antennas provided good reception from many South American stations, and the final selection included four stations from south of the magnetic equator.

Local interpreters were employed to help in the station selection and an operator was trained to change the recording tapes. Before departure from the Cabo Roja site, the system was placed in its automatic run mode to monitor 10 stations for one minute each at 10 minute intervals between the hours of 2300 and 0600 local time.

The recording equipment consist of a high-quality, programmable MF receiver; a mini-computer; and digital and voice cassette recorders as noted above. Various functions are controlled by the computer including frequency selection, timing, and antenna selection. The time is maintained by a battery-supported power source so that nominal power outages do not perturb future recordings.

## SECTION 3.5. APPLICATIONS

The constant study of EM wave transmission characteristics, the development of up-to-date theoretical and empirical models, and the study of real-world telecommunication problems lead to state-of-the-art applications for telecommunication uses. This section deals with a variety of programs which show the broad spectrum of applied electromagnetic sciences.

### 3.5.1. Antennas and Radiation

**HF Radar Transponder Communication.** Investigations of semi-passive communication at HF frequencies by means of modulation of backscattered radar returns were undertaken for the Naval Research Laboratory CHURCH EYE program. This program was terminated before completion, and the various elements of the work at ITS proceeded no further than initial start-up.

Table 3-2 Monitoring Summary for the Puerto Rico Site

MONITORING OF MF SKY WAVES AT CABO ROJA, PUERTO RICO

| f(kHz) | Time (Local) | Antenna* | Audible AM Signals | Recorded AGC/AM Audio | Most Likely Station | Power (kW) |
|---|---|---|---|---|---|---|
| 870 | | 3 | YES | YES | LRA, BUENOS AIRES, ARGENTINA | 100 |
| 1220 | | 3 | YES | YES | ZYJ458, RIO de JANEIRO, BRAZIL | 150 |
| 980 | | 3 | YES | YES | ZYH707, BRASILIA, BRAZIL | 300 |
| 870 | | 3 | YES | YES | RADIO CRESTOL<br>GUAYAQUIL, ECUADOR | 20 |
| 980 | | 2 | YES | YES | ZYH707, BRASILIA | 300 |
| 1130 | | 4 | YES | YES | BOGOTA, COLOMBIA | 20 |
| 680 | | 2 | YES | YES | HJBO ZAMBRANO, COLOMBIA | 100 |
| 738 | | 1 | (CARRIER) | YES | BARCELONA, SPAIN | 250 |

*ALL BEVERAGE ANTENNAS: 1≈95°T; 2≈140°T; 3≈165°T; 4≈180°T

The objectives of CHURCH EYE were to utilize sophisticated digital processing techniques in conjunction with a high-power USAF over-the-horizon radar to provide automatic target acquisition and tracking for surface ships at ranges of up to 1500 nmi. An essential element of the program, as defined, was to demonstrate the system facility in a simulated, tactical environment, where the actual tracking data were to be passed in real time to Navy fighting units in the surveillance area by covert modulation of the radar transmitted signal. The work by ITS was to provide resources for two corollary functions associated with this data transmission. These were to provide a unique identification--at the radar data output--of each of several friendly forces in the area, and secondly, to provide an inconspicuous data return capability from these forces to the radar. Both of these functions were to be provided by a ship-borne radar scatterer whose effective radar cross section was to be modulated. The processing characteristics of the coherent radar system are such that the return message data rate is necessarily quite slow; the information content, however, while vital is not overly complex in format.

The ITS efforts in this abbreviated program included overall system design, specification of the transponders to be constructed by an outside vendor, and initiation of design work on a ship-borne broadband antenna. The ITS also conducted preliminary long-range tests of a prototype system operating between the Erie (Colorado) test site and the Naval Research Laboratory MADRE over-the-horizon radar at the Chesapeake Bay. Design and construction of a multi-frequency, very-low-frequency modulator for use in the code generation of modulation of the transponder was also started.

Since the radar operates in a coherent mode, digital Doppler signal processing using fast Fourier transform techniques identifies targets in parameters of radar cross section (signal amplitude) and Doppler frequency (radial target velocity). By providing a near-resonant antenna on the target ship whose contribution to the overall target radar cross section is discernible, and by providing a mechanism for modulating the antenna cross section, a signal can be produced at the radar data output which has the characteristic of an identifiable pseudo target with a unique Doppler velocity. The Doppler width of this signal will be determined by the parameters of the Fourier transform being used and by ionospheric propagation perturbations. The information data rate possible with such a system is determined by the Fourier recycle period--typically, 10 to 50 second intervals--and by the number of resolvable Doppler frequency "slots," which in turn are determined by the factors noted above. (Clearly, an increase in the number of identifiable Doppler slots increases the information content of a multi-position code.)

The objective of this work was to implement and evaluate the concept of this passive communication system under realistic military operating conditions.

Radio Interference Survey For A GOES Satellite Receiving Terminal. The purpose of this project was to make a radio interference survey at the Federal Office Building in Kansas City, MO, for the Space Science and Engineering Center. The terminal will eventually receive signals from GOES satellites located at longitudes of 75°W and 135°W. The survey was needed to provide assurance that the receiving system would work at this site and not be seriously interferred with by other electromagnetic signals.

The equipment was assembled and tested at Boulder and transported to Kansas City, MO, and installed on the top of the 19-story Federal Office Building during April 1981. The measurement equipment consisted of the following items:

Spectrum Analyzer
Synthesized Signal Generator
X-Y Plotter
Scope Camera
Antenna Positioner
5' Parabolic Antenna
Helical-Conical Antenna.

Observations were first made with the broadband, wide beam width antenna and, when an interesting signal was observed, the 5' parabolic antenna with higher gain and narrow beam width was used to locate the signal source to within 1°. Measurements were made and recorded with the X-Y plotter and scope camera from 0-2 GHz to record all the signals present. The frequency range from 1670 MHz to 1700 MHz was of the most interest because the signal from the satellite would be at 1690 MHz.

Recordings were made for a 5-day period in April 1981, and the measurements were scheduled such as to cover a period of the four daily 6-hour time blocks.

The frequency range from 1670-1700 MHz was free of signals except for three sitings. Two of the sitings were from radiosondes released from Monett, MO and Topeka, KS. The third siting was a local signal coming from an antenna located at the Kansas City Light and Power Company and appeared to be a harmonic of their transmitted frequency. The direction of arrival and size of the signals were such as not to interfere with the GOES reception. Data results and conclusions were submitted as a letter report to the sponsor.

### 3.5.2. Transmission Through the Atmosphere: Applications

HF Broadcasting WARC Studies. The HF Broadcasting WARC will be concerned with the development of plans to effectively utilize the HF spectrum that is allocated for broadcasting services. The Institute has undertaken a number of projects to assist in the preparation of the United States positions for the Broadcasting WARC. This particular project is concerned primarily with the development of an improved HF propagation prediction program for radio circuits traversing the high latitudes; i.e., the latitudes north of 50° geographic. Many international broadcast circuits with transmitters in northern European and desired reception areas in the United States and Canada involve propagation of HF waves within and through the polar ionosphere. Physical processes that characterize the polar ionosphere can give rise to enhanced fading and enhanced absorption of signals passing through the polar ionosphere. This can lead to a reduction in the quality of service that is provided on the circuits out of Europe into North America. Similar reductions of service quality can occur on circuits from the Voice of America transmitters in Greenville, NC, directed toward Europe.

In order to properly plan the use of the frequencies allocated to the HF Broadcasting Service, it is necessary to develop methods whereby the manifestations of polar ionospheric processes and the polar ionospheric structure can be taken into account. This project has been directed toward incorporating selected features of the high latitude ionospheric structure into the Ionospheric Compatibility and Analysis Program [IONCAP]. The IONCAP program can be used to determine the predicted average performance of a HF radio circuit in terms of signal-to-noise ratio and circuit reliability. A method to specify the high latitude trough in F-region ionization has been incorporated into IONCAP. This permits a more realistic estimate of the decrease in maximum usable frequency that is associated with the trough to be calculated. In addition, a method to determine the enhanced absorption that is characteristic of auroral activity along a high-latitude circuit has been added into the IONCAP program. These additions enable IONCAP to be used in planning future HF broacast circuits as well as assessing in a realistic manner the performance of existing broadcasting circuits.

Region 2 MF Broadcasting Conference. The Institute has been instrumental in helping to prepare the U.S. position in preparation for the Region 2 MF Broadcasting Conference. Institute members participated in meetings in Washington, D.C., Ottawa, Canada and Fortaleza, Brazil to advise the International Frequency Registration Board concerning plans to test the compatibility and comparability of proposed changes to AM broadcast channeling.

The Institute participated directly in the development of versatile software components which would predict interregional interference at sites within the Western Hemisphere from high power transmitters located in other parts of the world. Included in this are routines to compute excess polarization coupling loss, sea gain, and diurnal periods of total darkness along a given path on the earth's surface. This entailed creating random access data bases of the high power stations in Europe, Africa and Asia, and Western Hemisphere coastline information. A diagnostic computer program was also converted to the Institute's batch processor. This program allows the Institute the capability of evaluating different channel spacing scenarios, inclusion of new stations in the free channels, and determining any interferences generated therefrom.

## CHAPTER 4. ADVANCED COMMUNICATION NETWORKS

This Division conducts a broad program of applied research and analysis of advanced communication networks. Division programs investigate technology options for developing competitive, lower cost communications networks to provide improved services and better resource utilization. This research incorporates technical, economic, market, regulatory, and policy factors in an integrated fashion. These studies, designed to assist NTIA policy, applications and spectrum programs, and the telecommunications research and applications needs of other Federal agencies, are focused on three categories:

Communication Protection,

Switched Networks, and

Specialized Networks.

Each of the sections below discusses those projects that relate to one of the above categories, and a summary of progress and results is given for each project.

### SECTION 4.1. COMMUNICATIONS PROTECTION

The Communications Protection program was initiated by NTIA in fiscal year 1979 after Presidential Directive PD-24 designated the Secretary of Commerce as one of two Executive Agents. The Secretary delegated responsibility to the Administrator, NTIA. The program is directed by the NTIA Special Projects Office (SPO), a unit within the Office of Federal Systems and Spectrum Management in Washington. The SPO develops policy recommendations and conducts telecommunication surveys of the federal agencies. Technical support functions of the program, including system analyses, policy support, and survey support, are performed by ITS in Boulder.

Presidential Directive PD-24 provided certain policy guidelines that included:

1. Government classified information relating to national defense and foreign relations shall be transmitted only by secure means.
2. Unclassified information transmitted by and between government agencies and contractors that would be useful to an adversary should be protected.
3. Nongovernmental information that would be useful to an adversary shall be identified and the private sector informed of the problem and encouraged to take appropriate protective measures.

The Secretary of Defense, the other PD-24 executive agent, has assigned the National Security Agency (NSA) the responsibility for protection of classified information, as well as national security related unclassified information. The Department of Commerce (NTIA and ITS) is addressing the protection of nonnational security related, unclassified information. Examples of this type of information are as follows:

- o Financial Information
  - o Planned changes in prime interest rates
  - o Support of the dollar in foreign exchange markets
- o Commodity Market Forecasts
- o Supply of Critical Materials
- o Strategies for International Negotiations
- o Selected High-Technology Information.

The principal threat to telecommunications information is the vulnerability of both terrestrial and satellite microwave radio to eavesdropping by foreign adversaries.

Although many aspects of the Communications Protection program are classified, the following unclassified specifics are provided to offer an insight into FY-81 efforts. The topics described below fall into general work categories established within the program:

1. Reference Microwave Propagation Loss Model
2. DES and Federal Standards Efforts - Communication Protection Standards Project
3. Terminal Evaluation Project
4. Analog vs. Digital Link Analysis - Common Carrier Networks Project
5. Public Key Cryptography and its Implementation - Public Key Project.

#### 4.1.1. Reference Microwave Propagation Loss Model

In order to predict the propagation loss over point-to-point paths in the 2 to 11 GHz frequency range, a reference microwave propagation loss model has been developed. This model is used to compute the biased median estimate for the propagation loss. At microwave frequencies, significant terrain features may be treated as sharp knife-edge obstacles. Any number of knife-edges may be found along any particular propagation path, but only a few of these knife-edges may be of significance in calculating the path attenuation.

All paths can be characterized as one of three types:

1. radio line-of-sight (LOS),
2. single horizon (SH), or
3. double horizon (DH).

In the LOS case (see Figure 4-1), the transmitter and receiver are within radio line-of-sight of each other, yet the tops of intervening knife-edges may approach close to the direct ray. In certain situations this could cause the signal to attenuate well below the freespace value. For example, with an LOS path having 4 knife-edges near the direct ray, it is possible for the theoretical attenuation to be almost 14 dB greater than the free-

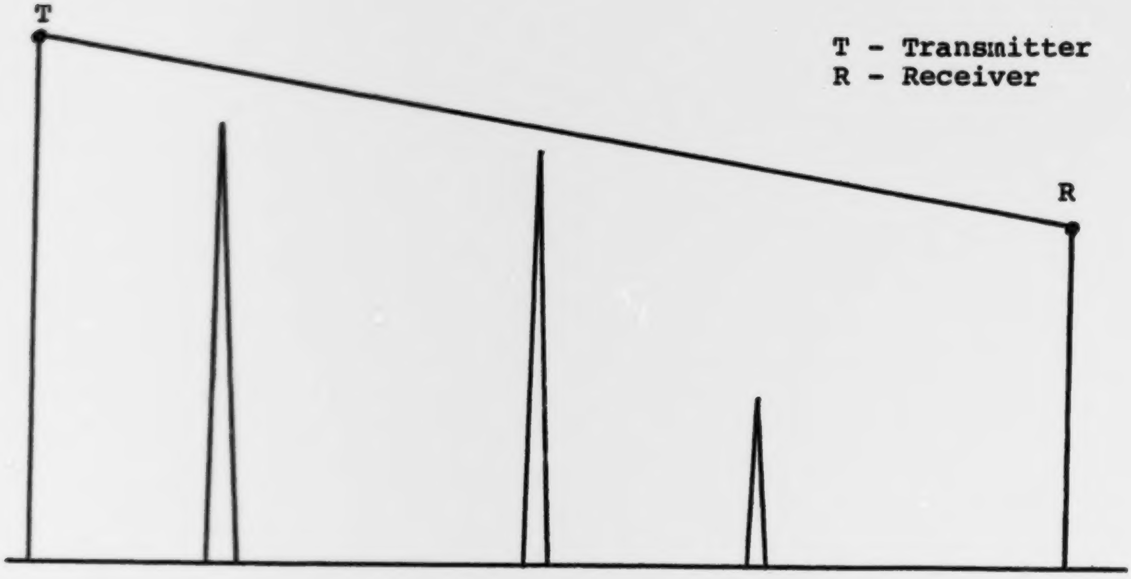
T
R
T - Transmitter
R - Receiver

Figure 4-1. Geometry for a line-of-sight (LOS) path.

space loss. This phenomenon may account for some of the "unusual" LOS signal measurements occasionally obtained.

In a single horizon path (see Figure 4-2), one obstacle or knife-edge serves as a common horizon for both the transmitter and receiver. Again, the tops of intervening knife-edges may approach the transmitter-to-horizon direct ray and/or the horizon-to-receiver direct ray causing significant effect on the radio signal. If the intervening knife-edges are all well below the direct rays, the attenuation is given by the standard single knife-edge diffraction theory.

A double horizon path (see Figure 4-3) has separate horizons for the transmitter and for the receiver. Of course, intervening knife-edges can occur anywhere along the path, but it is apparent that those in the middle section (from horizon to horizon) can have an especially significant effect on the signal. These knife-edges, if they occur, can not only approach the horizon-to-horizon direct ray from below, but can actually rise above the ray reducing the signal even further.

A multiple knife-edge diffraction theory has been derived recently and a computer program written to calculate attenuation values. The program will accept up to 10 knife-edges and computes the resulting magnitude of the attenuation relative to freespace. From the terrain profile of the path, the antenna heights, knife-edge obstacle heights, and separation distances are read in as input parameters together with the radio frequency. The program then selects those knife-edges which are significant and gives the resulting attenuation as output.

The reference loss model, based on multiple knife-edge theory, should provide better estimates of propagation loss than the previously used interim loss model. For many paths the results will be the same, but, especially in the case of double horizon paths, the reference model will give more accurate results.

### 4.1.2. DES and Federal Standards Efforts

On January 15, 1977, the National Bureau of Standards through its Federal Information Processing Standards Publication (FIPS PUB) 46, announced the "Data Encryption Standard" (DES). The DES specifies an algorithm to be implemented in electronic hardware devices and used for the cryptographic protection of sensitive, but unclassified, information.

Data to be cryptographically protected is called plain text. Encryption is the process of transforming plain text into cipher text (or unintelligible text). Decryption is the inverse of encryption; i.e., transforming cipher text into plain text. The DES is a block cipher, or one which operates on fixed size blocks of symbols. During encryption it maps (transforms) 64-bit plain text input blocks into 64-bit cipher text output blocks. There are $2^{56}$ possible mappings. Each is unique and invertible. The specific mapping utilized is determined by a 56-bit keying variable, which is entered by the user. In order to successfully decrypt, one must know which of the $2^{56}$ possible keying variables (or keys) was used to encrypt the information. This information is normally known only to the originator and the intended receiver of the encrypted message. In addition, with a properly designed algorithm, such as the DES, there are no known shortcut methods of determining the correct keying variable, except for exhaustive search of all possible keys.

The Institute has been actively involved in the development of standards related to use of the DES for telecommunications protection. Federal and American National Standards, as well as FIPS PUB's, are being generated which apply the DES. NTIA is supporting on-going efforts by other agencies, and initiating effort in areas not addressed elsewhere. As NTIA's technical arm for protection standards, ITS has worked closely with the National Communications System (NCS), the Federal Telecommunications Standards Committee (FTSC), the National Bureau of Standards (NBS), the General Services Administration (GSA), and the National Security Agency (NSA).

The Institute was a strong supporter of NBS's FIPS PUB 81, "DES Modes of Operation." This FIPS defines the authorized modes under which DES devices can operate; i.e., electronic codebook, cipher-block chaining, cipher-feedback, and output feedback. It was approved by the Secretary of Commerce on October 30, 1980.

Proposed Federal Standards (pFS) 1025 and 1026 refer to FIPS PUB's 46 and 81 and standardize interoperability requirements for use of the DES in data communications. pFS 1025 specifies the requirements for the Network and Transport layers of the International Organization of Standardization's (ISO) Open Systems Interconnection Reference Model, while pFS 1026 specifies the requirements for the Physical and Data Link Layers of the ISO model. The Institute cooperated with the principals of the FTSC to bring these proposed standards to the stage where they have now been offered to the public for comment through the Federal Register. Approval of the standards is expected in FY 82.

Federal Standard 1027 dictates the physical security requirements for devices employing the DES in a telecommunications environment. Approved by the FTSC in May 1981, this standard brought to fruition years of work by ITS, NSA, GSA, and the NCS. Because of the special role the Department of Commerce plays in PD-24, Federal Standard 1027 states that all Federal departments and agencies planning to use DES cryptographic equipment to cryptographically protect non-national security related information shall coordinate their plans with NTIA. Such coordination is required to insure that the security provided by the Standard is not degraded by improper implementation or use. The Institute provides the technical expertise to allow other Government agencies to protect themselves, and adhere to FS 1027.

Besides the support that ITS has provided for the Standards efforts described above, work was initiated at the Institute to provide

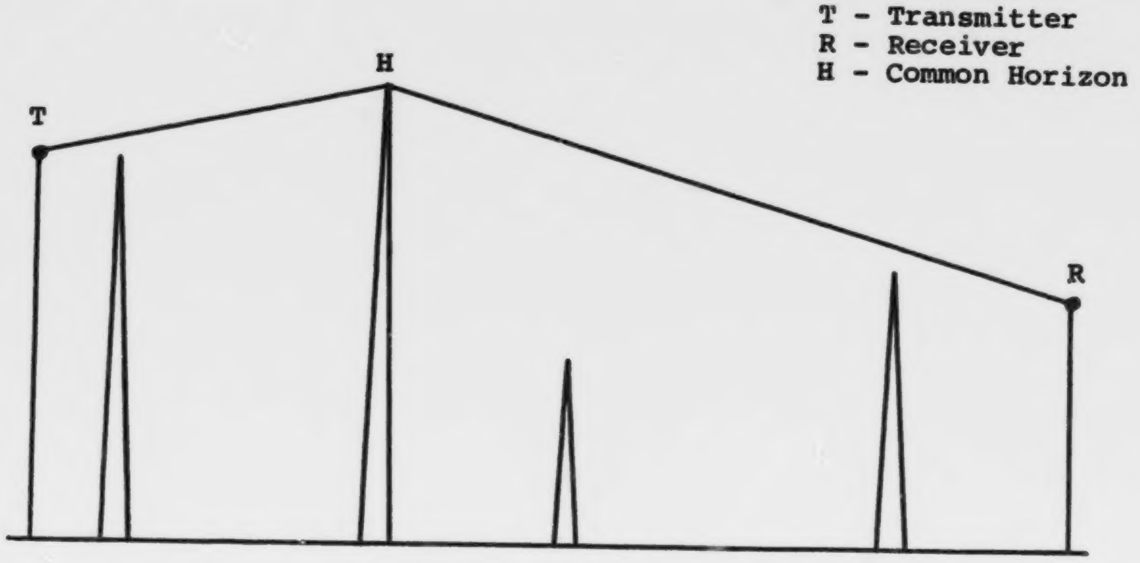
T - Transmitter
R - Receiver
H - Common Horizon
H
T
R

Figure 4-2. Geometry for a single horizon (SH) path.

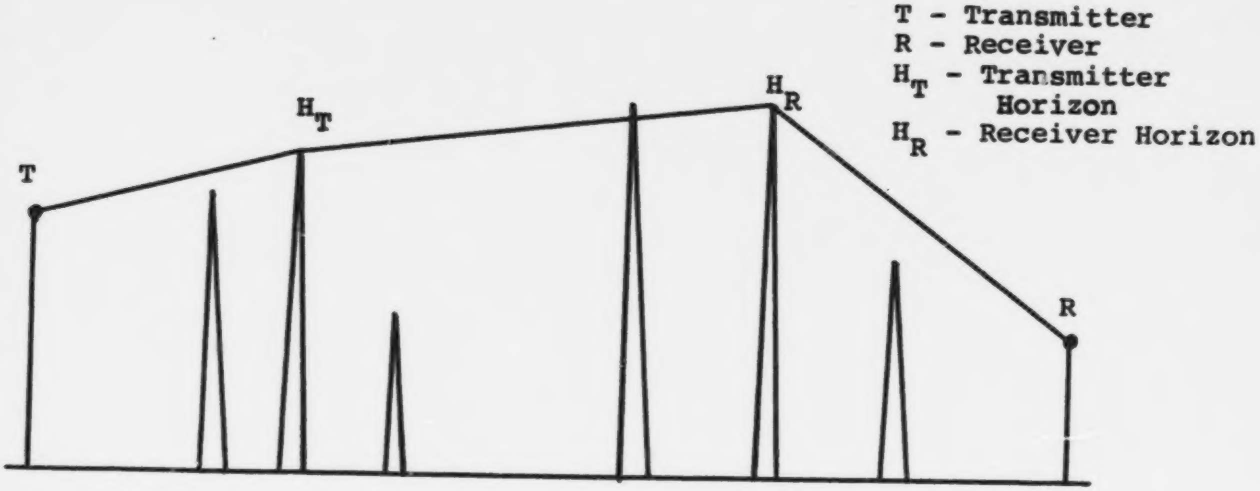
T - Transmitter
R - Receiver
$H_T$ - Transmitter Horizon
$H_R$ - Receiver Horizon
$H_T$
$H_R$
T
R

Figure 4-3. Geometry for a double horizon (DH) path.

guidance for DES users in the areas of key generation and key distribution. Ever since the original certification of the DES by NBS, the proper generation of keys for systems using DES has been an important requirement. Despite the substantial protection that the DES algorithm offers, it is recognized that certain keys are less desirable than others, and could conceivably cause an undesirable impact on the effectiveness of the DES based device (i.e., double encryption of plain text using certain keys will yield plain text, thereby compromising the entire cryptographic system). Proper key generation, then, is essential. Safe, convenient distribution of keying material is also a very real concern in establishing an effective protection system.

A proposed standard on key generation has been written by the Institute. This document is viewed as a good first draft for a Federal Standard and for an American National Standard. A proposed NTIA report will describe in detail the standard's underlying foundation. Although the report demonstrates that the technical considerations of the standard are presented in sound mathematical terms, there is a heavy emphasis placed on observing engineering principles. Consequently, the standard is one which can be easily implemented in off-the-shelf hardware. In fact, ITS has designed, constructed, and tested an engineering model of the standardized key generator.

A follow-on to the key generation system development was a key distribution system. A proposed standard on cryptovariable distribution was written, and will be explained in a future NTIA report. Like the key generation standard, this standard was designed to allow relative ease of hardware formulation. Two prototypes were designed and constructed by ITS, and were successfully tested using basic, unconditioned telephone lines. The distribution system was integrated with the key generation system, then, to allow a new key for a communication link to be distributed electronically using a public-key distribution scheme.

### 4.1.3. Terminal Evaluation Project

One of NTIA's responsibilities under PD-24 is to coordinate with and advise Federal agencies planning to cryptographically protect sensitive non-national security related information to insure that systems employing cryptographic equipment are correctly implemented. This effort is especially important in view of the fact that a complete set of Federal standards relating to the encryption of various types of information has yet to be adopted.

Numerous devices are currently being marketed for use in the protection of various forms of electronic communications. This equipment ranges from devices for the protection of voice and data communications to ancillary equipment consisting of cryptovariable generation devices and devices designed for the transport of keying variables. A government agency which may wish to implement protection has a large variety of equipment to choose from and, in the absence of Federal Standards, little guidance. Many such users may be unfamiliar with the technical and performance characteristics of this equipment. They must rely solely on information which may be provided by the vendors of such equipment for making decisions on its application and use.

The objective of this Terminal Evaluation Project is to examine several basic questions from a user's viewpoint. These are:

- Does the equipment conform to applicable FCC rules and regulations and industry standards for communications equipment?
- What communications system performance advantages/disadvantages does use of the equipment provide the user?
- What Federal standards, or portions thereof, applicable to such equipment, does the equipment meet?
- Are there certain installation and/or operational configurations which should be avoided by the user?

No attempt is being made by NTIA/ITS to evaluate the level-of-protection provided by a particular item of equipment. The study includes DES based encryption equipment designed for protection of data, and both analog voice scramblers and digital voice encryption equipment. Certain other related techniques will also be studied.

A total of 18 separate items of equipment from six major manufacturers has been procured to date. This equipment comprises seven different protection systems. The procurement of this initial group of equipment was completed during FY 81. A general plan for the study of these protection terminals was also completed during the past year. In addition, studies of two DES based data encryption systems were completed. These studies involved not only the encryption equipment but special devices developed to aid in key management as well.

### 4.1.4. Analog vs. Digital Link Analysis

There are several basic approaches under consideration for protection of common carrier telecommunications information. This is because common carriers (like AT&T, MCI, etc.) employ analog FDM-FM technology for the vast majority of terrestrial and satellite microwave radio links, but are also using all-digital links to some extent, and are seriously considering the use of analog SSB-AM. The use of different modulation techniques adds a degree of difficulty to the search for proper protection approaches. Because of this, the Communications Protection Program has designed a two-stage study effort to ensure that all significant factors are considered before protection schemes are recommended as part of a comprehensive National Strategy Plan for protection. The first stage involves strictly a theoretical comparison of analog and digital techniques which could be used for common carrier terrestrial and satellite microwave systems. The second stage involves the practical comparisons of implementation, performance, and cost of such systems.

BEST DOCUMENT AVAILABLE

Stage 1 - Theoretical Comparisons: A number of techniques have been proposed to upgrade microwave telecommunication systems from analog to digital. Some theoretical work has been published in the literature, but the analysis is incomplete and fragmented. Substantial technical issues have not been addressed fully, including total link/system performance, spectrum utilization, and levels of complexity between various system schemes. A complete study must present all applicable digital systems. The Institute is pursuing this study effort through internal ITS research supplemented by information derived from a private consulting firm.

The contract work compared standard analog FDM/FM links against digital systems using such modulation techniques as biphase, quadrature, and m-ary PSK; binary and m-ary FSK; quadrature AM; quadrature partial response AM; and minimum-shift-keying. Data formats were studied (NRZ, duobinary, etc.) as well as voice digitization techniques (companded PCM, ADM), channel sharing (time assignment speech interpolation), diversity, error-control coding, and multiplexing (TDM, DAM, CDM, and FDM). The systems studied were compared on the basis of quality of transmission and efficiency of spectrum utilization in the presence of thermal noise, interference, fading, and other germane factors. The consulting firm concluded that, with all factors considered, minimum-shift-keying should be the choice digital modulation technique for the present state-of-the-art radios in the 4, 6, and 11 GHz bands. The Institute is continuing its research in this area.

Stage 2 - Practical Considerations: Protection provided to common carrier microwave links should be at the least cost, and cause no link performance degradation. These criteria are important both to the carriers and their customers. It is not yet clear, however, what the investment (cost) and performance tradeoffs are for implementing protection to existing analog links, analog links modified for digital transmission, or completely different new links. A study contract to another consulting firm will provide many of the facts necessary to form a logical approach toward protection implementation.

This "real-world" study effort primarily involves three related tasks:

(1) Formulation of technical descriptions for existing common-carrier analog links, and evaluation of the relative performance of the links.

Eight different terrestrial and satellite analog links, including Bell System and CCITT types, will be specified. Baseband and radio-frequency information, multiplexing, and antenna characteristics will all be described. Block diagrams (schematics) will illustrate equipment in each system, manufacturer's part/model numbers, equipment cost, interface characteristics, input/output levels, etc. A relative level of performance will be computed for each of the analog links. That is, based on the link configuration, equipment used, modulation technique, etc., the performance the link could potentially have will be determined. Then this potential will be compared against carrier published performance. The Grade of Service concept will be used to determine minimum acceptable voice channel objectives. And the normal mix of voice, data, and facsimile traffic found on common carrier links will be determined.

(2) Theoretical transformation of the analog links described in Task (1) to digital links using various modulation techniques, and comparison of analog and digital links:

Task (2) treats the links of Task (1) as reference links and substitutes different modulation techniques in the links. The intent is to evaluate link performance, and cost impact, if some common-carrier, analog, broadband channels are converted to digital, broadband channels (while analog channels still operate adjacent to the digital channels); if some analog FDM-FM links are converted to single-sideband AM links; and if entire analog links are converted to digital links. The modulation techniques listed in the "Stage 1" effort above apply here also.

(3) Design of optimal analog and digital links to replace the links described in Task (1):

The existing common-carrier links described in Task (1) are reviewed to determine the minimum operational requirements of each link; then an FDM-FM analog and a digital system are designed to replace each one. The intent here is to conceptually develop links which will deliver optimum performance for mixed voice/data/facsimile traffic. Only equipment which is commercially available, or is under development and will be commercially available within three years, will be considered for the "optimum links." Optimization is assumed to be as follows. For analog systems, the number of baseband channels in the broadband channels shall be optimized while maintaining a signal-to-noise ratio at least as good as the referenced link. For the digital system, the bandwidth efficiency shall be optimized.

The Stage 2 efforts will be completed by December 1981.

### 4.1.5. Public Key Cryptography and its Implementation

One of the most exciting results from public cryptographic research is the public key cryptographic system (PKCS). Generically, a PKCS is a method by which two parties can derive a common secret number quantity (e.g., a number or string of bits) without previously agreeing on anything in secret; i.e., all of the transactions are publicly disclosed. A PKCS depends upon asymmetric complexities in computation of mutually inverting operations. This curious aspect has been dubbed a cryptographic 'trapdoor.' In essence it means that, for some computations, one may proceed forward on a one-to-one mapping with relative ease and attendant small computational expense, but one is apparently faced with an enormous work factor to effect the inverse mapping in general, even though the unique inverse mapping exists.

It is believed that the various PKCS's deserve study as candidate vehicles for protected Data Encryption Standard (DES) cryptovariable transmission.

### 4.1.6. MITRE Public Key

The MITRE Public Key Cryptographic System (MPKCS) is ideally suited to the ever-expanding world of digital communications.

The MPKCS requires both parties to derive secret numbers, x, and y, which serve as exponents of a publicly disclosed element, $\alpha$, of a finite field of $2^n$ elements. Exponentiation is performed modulo a GF(2) primitive polynomial (also publicly disclosed) of degree n. The first party calculates $\alpha^x$ and sends it to the second party. It is assumed that public disclosure also takes place. The second party computes $\alpha^y$ and sends it to the first party. Here it is also assumed that public disclosure takes place. The first party then exponentiates $\alpha^y$ to the x power and the second party exponentiates $\alpha^x$ to the y power. Both parties then obtain $\alpha^{xy}$. An eavesdropper cannot compute $\alpha^{xy}$ without having x or y and x or y can only be obtained by solving for x or y given $\alpha^x$ or $\alpha^y$. The asymmetric complexity is that given $\alpha$ and x one can easily compute $\alpha^x$, but given $\alpha^x$ and $\alpha$ one cannot, apparently, easily recover x.

The Institute's work in public cryptography during the last year continued with extensive study of the MITRE Public Key Cryptographic System (MPKCS). The MPKCS appears to be an excellent cryptographic vehicle for protecting the transmission of Data Encryption Standard (DES) cryptovariables, i.e., keying variables and initialization vectors. Primarily, ITS has been carefully examining the strengths and weaknesses of the MPKCS under the threat assessment appropriate to NTIA's role in PD-24 activities. We have implemented the MPKCS in microprocessor software and successfully experimented with the system over unconditioned telephone lines at a moderate signaling rate. These experiments have provided valuable insight into the time critical aspects of using the MPKCS. Elements which ITS is presently resolving are: (a) refinement of the cryptographic protocol and (b) the selection of the specific polynomial modulus of the system. The first item concerns the functional procedure to be implemented to defeat relevant attacks. The second is guided by the threat scenario and also by engineering considerations regarding ease of implementation.

The Institute has developed and published (J. Hershey, see Publications Annex) a method through which the initial exponentiations required by the MPKCS can be accomplished quickly if a particular polynomial modulus ($x^{127}+x+1$) is selected. Because of the possibility that this particular modulus may be discarded after further analysis, we are working on new implementations for the system that can be executed quickly, if not in software, at least in hardware.

We have completed a draft report on the MPKCS which will be published in the near future. The report is a primer on the system and includes a study of the underlying mathematics. It also includes a security analysis and architectural aids that will prove useful no matter what particular implementation is finally selected. This report is currently undergoing the prepublication review process.

### 4.1.7. Rivest, Shamir, and Adleman (RSA) Public Key

The Publication of "New Directions in Cryptography" by Diffie and Hellman has generated an increasing amount of research on public key cryptosystems. The system introduced by Rivest, Shamir, and Adleman is the subject of this project.

Briefly, the RSA scheme requires choosing two large primes, p and q, each about 100 digits long, and an encryption exponent E. Let n = pq. Then, to encrypt a message P, raise P to the power E and find the remainder upon division by n, or in symbolic form, the cipher text C is given by

$$C \equiv P^E \bmod n. \qquad (1)$$

Decryption depends on finding a number D such that

$$C^D \equiv P \bmod n. \qquad (2)$$

The numbers E and n are made public, while the members p, q, and D are kept secret. Anyone knowing D can find p and q. Thus, the basic security of the algorithm relies on the knowledge that factoring a number n which is a product of two larger primes is presently a very difficult problem.

One of the objectives of this project is to examine factoring methods to see if improvements are possible, and to look at other potential cryptographic weaknesses in the RSA algorithm. To date, no serious shortcomings have been found.

Two additional goals are to identify areas of application of the RSA cryptosystem and to design efficient implementations of the algorithm. One of the promising applications is for distribution of keys for conventional cryptosystems such as DES.

An efficient multiple precision arithmetic package has been developed under contract and installed on ITS's CDC 750 computer. The software enables computations to be performed on the CDC 750 using numbers of the size required to investigate and implement the various public key cryptosystems.

An NTIA report entitled "A Critique of Some Public Key Cryptosystems" will be published by ITS. This report presents a detailed overview of the RSA public key system (RSA-PKS) and another public key system based on the "knapsack" problem. The report also gives detailed information on a computer implementation of the RSA-PKC which uses the multiple precision arithmetic package described earlier. This implementation includes a routine for finding primes P such that

$$p = 2p' + 1 ,$$

with p' a prime, and with p + 1 having a large prime factor. A review of some factoring techniques is also given.

A second paper is being prepared which will discuss results of an investigation of the potential of "Monte-Carlo" factoring schemes for the special case of numbers of the form

$$N = (2p' + 1)(2q' + 1)$$

with p' and q' primes was also written. The conclusion is reached that the special form of N does not offer an advantage for "Monte-Carlo" factoring.

An effort is also underway to investigate ideas given by Adleman for finding discrete logarithms. This is part of a continuing study of the applicability of using the MPKCS to encrypt cryptovariables for electronic distribution.

## SECTION 4.2. SWITCHED NETWORKS

The Switched Networks group of the Advanced Communication Networks Division is involved with a number of programs which relate to common carrier issues. These programs include work for other agencies such as the Department of the Army and the U.S. Postal Service, as well as the Domestic Common Carrier Program within NTIA. The NTIA common carrier policy is oriented towards increasing competition, decreasing regulation, and stimulating innovative telecommunication services and productivity. As the telecommunications industry moves in these directions, there is an increasing need in NTIA for the capability to 1) address those technical issues whose understanding is integral to the formulation of sound policy, and 2) resolve those technical issues which impede the implementation of such policy.

As the central federal resource for telecommunications research and engineering, ITS is in a unique position to satisfy these needs. Increased competition implies both present and new service offerings will be supplied less by a single network which is under centralized planning and management and more by competing networks which are under different ownership. Decreased regulation implies that these networks will function in an environment which is under less government oversight and control.

Given this background, the objectives of this activity to provide technical support to common carrier issues are twofold: first to understand the interactions between competing networks, and second to facilitate the interoperability of competing networks. Pursuant to these objectives, four types of work can be defined. These are: 1) understanding the underlying technologies and methodologies, 2) modeling composite networks, 3) recommending policy changes and modifications, and 4) devising minimal remedies consistent with policy.

The Switched Networks Group is directly involved in the first two items, with the major support from agencies in the Department of Defense. Many of the problems encountered in the military environment are similar or identical to those found in the private sector. Understanding the advanced network technologies currently being developed by the military departments provides important insight to advanced network alternatives with commercial possibilities and to the potential policy issues which may require resolution in the future.

In the following paragraphs we describe the program elements being conducted by the group to support this activity.

FCC Code and Protocol Inquiry. A major part of the ITS FY 81 Common Carrier Technical Support program was directed towards interpreting and refining the Federal Communication's Commission's Final Decision in the Second Computer Inquiry. In that decision, the Commission divided common carrier communication services into two categories: basic services, which provide essentially transparent transmission of subscriber information between designated points; and enhanced services, which act on the subscriber information, provide additional, different, or restructured information, or involve subscriber interaction with stored information. The Commission ruled that basic services are regulated under Title II of the Communications Act of 1934, whereas enhanced services are not. The Commission also established a structural separation policy under which carriers with potential monopoly power are allowed to provide enhanced services only through a fully separate, unregulated corporate subsidiary. This FCC policy is intended to minimize government regulation of communications and to promote the development of efficient, innovative enhanced services through market competition.

In its Final Decision in the Second Computer Inquiry, the FCC discussed, but did not resolve, the issue of whether certain "low level" code and protocol conversions should be allowed in conjunction with basic services. In December of 1980, the Commission instituted a new inquiry (Digital Communications Protocols, General Docket 80-756) intended to address that issue. This inquiry is significant because it will determine the permissible scope of basic service offerings and, ultimately, the partitioning of carriers subject to the separation requirement.

The Institute submitted two filings to the FCC in connection with the code and protocol inquiry. The first stated three basic conclusions (NTIA filing on FCC General Docket No. 80-756, March 31, 1981 by Seitz and Linfield). The Institute concluded, first, that a total prohibition on code and protocol conversion in conjunction with regulated basic services is a practical impossibility: exceptions are required even to allow AT&T's existing public telephone network to function. The filing

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presented several specific examples of existing voice network functions which involve code and protocol conversion. The Institute concluded, second, that no definitional method of identifying allowable conversions would be both reasonable and enduring. The filing evaluated eight proposed definitional criteria on the basis of the FCC's regulatory objectives, and demonstrated serious deficiencies in each. On the basis of these difficulties, NTIA concluded, finally, that a waiver process described in the Commission's Reconsideration Order in the Second Computer inquiry should be the primary mechanism for considering exceptions to the conversion prohibition. The Institute also proposed specific definitions for a number of important technical terms which were not clearly defined in the Second Computer Inquiry: e.g., "subscriber information" and "communications protocol."

The second NTIA/ITS filing in the code and protocol inquiry (NTIA filing on FCC General Docket No. 80-756, July 1, 1981 by Seitz) summarized the positions of all other respondents on the three conclusions stated in NTIA's first filing, commented in detail on AT&T's initial filing, and made procedural suggestions for advancing the inquiry towards a successful conclusion.

The Institute's summary of other respondent positions reinforced the view that substantial reliance on the waiver process is unavoidable. The summary demonstrated, first, that most respondents accept the need for at least some "basic" conversions; second, that no satisfactory method of identifying allowable conversions has been suggested; and third, that most respondents favor specific waivers over general definitional criteria to the extent that exceptions to the conversion prohibition are needed.

In commenting on the AT&T filing, NTIA showed that a definitional criterion based on the distinction between "user-to-user" and "network control" information would not sufficiently restrict allowable conversions and would not allow necessary exceptions. The NTIA filing also pointed out that no definition for the key term "conversion" has been established, and proposed a simple mathematical definition for that term.

The Institute's second filing made two procedural suggestions for advancing the code and protocol inquiry towards a successful conclusion. The Institute suggested, first, that the analysis of possible exceptions should be inductive rather than deductive; i.e., participants should first develop a comprehensive understanding of specific cases in which "basic" code and protocol conversions may be required, and then develop general exception criteria if experience shows that such generalizations are possible and useful. An inductive approach has been followed in the inquiry to date. The Institute also suggested a possible method of expediting the inquiry: an ad hoc Technical Advisory Committee, comprised of recognized experts from industry and government, charged with developing a compendium of existing network conversions.

USPS Electronic Message Service System. The NTIA/ITS has for the past several years been supporting the development of Electronic Mail Systems. Under the second phase of a multi-year agreement between the USPS and the NTIA, the ITS has continued to provide technical support and system analysis to formulate concepts and to select candidate systems from a number of alternatives which best meet the overall USPS objectives. The current agreement supports certain requirements for the short and long term development of Interconnection Standards, supports the current USPS Electronic Computer Originated Mail (E-COM), and provides for engineering assistance with quick reaction time to the USPS Office of Electronic Mail Systems Development.

Guidelines and standards concerning interconnection to serving post offices (SPO's) are described below. The development and demonstration of interconnection standards for services are also covered. In the following paragraphs the engineering assistance project accomplished to date for the E-COM project office is described.

The USPS plans to implement E-COM service for 25 SPO's early in 1982. The E-COM system is expected to handle approximately 70 million messages per year by the third year of operation. (A message consists of one to two pages of text with 1200 characters per page). Messages may be delivered to the system via U.S. domestic common carriers or on magnetic tape pending Postal Rate Commission approval. The customer will send messages to the destination city SPO through the common carrier of his choice where the messages will be stored on magnetic tape prior to printing. After processing, sorting, and printing, the messages are delivered physically as conventional first class mail no later than the second day after acceptance (Figure 4-4).

Although telecommunication facilities have not been authorized for use in carrying messages between SPO's it is still of interest to examine the cost of available communication alternatives and to compare these costs with the current cost of Express Mail.

Five basic common carriers have been considered for comparing message costs. They are dial-up lines, leased lines, value-added networks and satellite systems. In addition certain hybrid combinations of these have been examined. The results are summarized in the table below which indicates the total estimated cost in cents/message for the various systems considered.

Of course, a number of critical assumptions were made to derive these costs. For example, one assumption is the message volume to be transferred on the average day between city pairs and the transfer rate. The sensitivity of the various assumptions has been evaluated and in many cases parametric curves developed to indicate cost variations with changes in traffic volume and other critical parameters.

Work such as this is continuing on an as needed' basis along with other program efforts described below.

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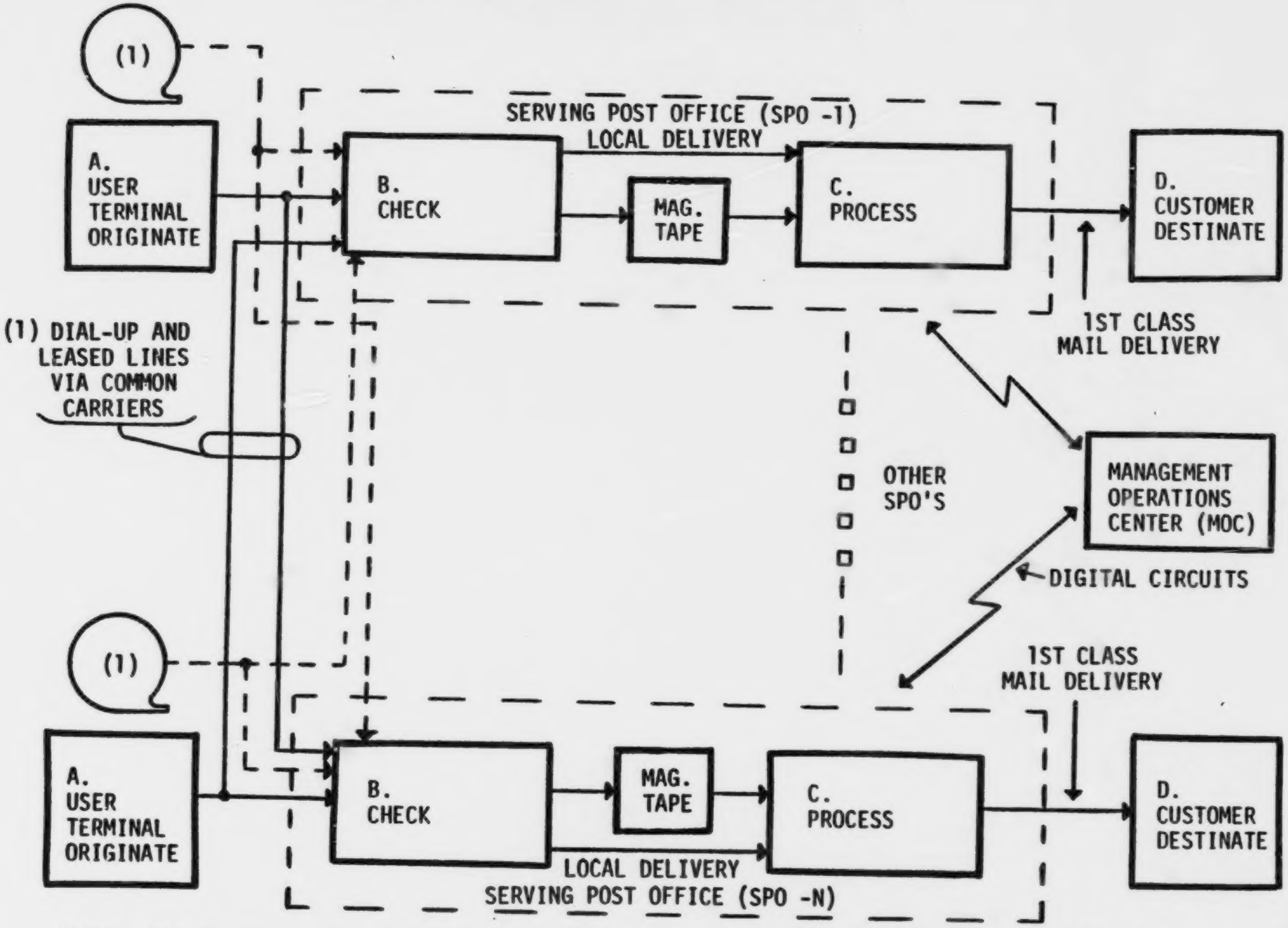

(1)
A. USER TERMINAL ORIGINATE
B. CHECK
SERVING POST OFFICE (SPO -1)
LOCAL DELIVERY
MAG. TAPE
C. PROCESS
D. CUSTOMER DESTINATE
1ST CLASS MAIL DELIVERY
(1) DIAL-UP AND LEASED LINES VIA COMMON CARRIERS
OTHER SPO'S
MANAGEMENT OPERATIONS CENTER (MOC)
DIGITAL CIRCUITS
(1)
1ST CLASS MAIL DELIVERY
A. USER TERMINAL ORIGINATE
B. CHECK
MAG. TAPE
C. PROCESS
D. CUSTOMER DESTINATE
LOCAL DELIVERY
SERVING POST OFFICE (SPO -N)

NOTE: (1) Magnetic tape and private lines input to E-COM will be implemented pending PRC approval.

Figure 4-4. E-COM service operation.

| Alternative Network Configuration | Total Estimate Cost in Cents/Message |
|---|---|
| Dial-Up Lines | |
| o Daytime (8 AM to 5 PM) | 2.6 |
| o Evening (5 PM to 11 PM) | 1.7 |
| o Night and Weekends | 1.0 |
| Leased Lines | |
| o Fully Connected | 10.4 |
| o Loop | 1.5 |
| o Structured | 1.3 |
| o Star | 0.9 |
| o Mesh | 0.9 |
| o Tree | 0.8 |
| Value-Added Network | |
| o Packet Switched | 1.6 |
| Satellite Systems | 16.3 |
| Hybrid Networks | |
| o Leased Access and Satellite Backbone | 3.7 |

Work was undertaken last year in response to a Federal Administration Policy Statement (July 19, 1978) and an USPS Board of Governors Resolution (Resolution 80-5).

One administration condition requires, "To ensure that interconnection with the mail delivery system is available to all companies, technical interconnection standards should be developed through a cooperative effort by the American National Standards Institute, the USPS, the private carriers, and an impartial arbiter, if needed."

The Board of Governors resolution adheres to that guideline by stating that the USPS will:

1. Issue standards for the technical interconnections (speeds, codes, protocols) between carriers and SPO's.
2. Negotiate standards on quality, scope, and duration of carriers transmission service as part of its interconnection contracts.
3. Require any common carrier to connect with all SPO's if carrier meets other standards and is able to do so.
4. Contract for the transmission services of one or more carriers if there is a demonstrated need for the service under terms and conditions which preserve free and open competition in the transmission phase of the E-COM system.

The Institute's responses to these guidelines have emphasized the preparation of documents which will be used for the adoption of interconnection and performance standards for the USPS E-COM service.

The applicable coding, signaling, and transmission standards for the E-COM service at this time are:

1. Asynchronous input over dial-up access lines will use:
   a. the American National Standard Code for Information Interchange (ASCII), ANSI X3.4-1977,
   b. operating full-duplex mode, at
   c. 300 or 1200 b/s signaling rate and entering information from an on-line storage device.
2. Binary synchronous communication (BSC) over dial-up access lines will use:
   a. the Extended Binary Coded Decimal Interchange Code (EBCDIC),
   b. operating at half-duplex, at
   c. 2400 or 4800 b/s signaling rate.
3. Digital data communications message protocol will use dedicated lines with:
   a. the ASCII code,
   b. operate full-duplex mode, at
   c. 56,000 b/s.

A number of reports and technical action statements have been prepared which identify telecommunication interconnection standards applicable to the E-COM system; recommendation of values, test procedures and equipment for transmission performance evaluation; a review of domestic common carriers; means and sources of implementing CCITT Recommendation X.25 to a packet-switched network; an evaluation of the tradeoffs of available interfaces at the physical layer of the International Organization for Standardization's (ISO) Open Systems Interconnection (OSI) reference model. Some of the papers that have been delivered to the USPS during the past year include:

Need for Telecommunication Standards for Interconnection with the U.S. Postal Service EMSS, by D.V. Glen and R.E. Thompson, NTIA Report 81-62.

Guidelines to Telecommunications Interconnection Requirements for Message Input to the USPS E-COM System, by D.V. Glen, NTIA Report 81-73.

Other activities are the participation in American National Standards Institute (ANSI) activities. This has included membership in ANSI Task Group X3S37 (Public Data Networks), attendance at meetings during alternate months, hosting a meeting of X3S37 in Boulder, and contributing a paper which was submitted to the ISO. The paper by D.V. Glen was the first attempt at showing a relationship between the ISO OSI reference model network layer service primitives and reference events of the User-Oriented Data Communications Performance Parameters (FS 1033, now being considered as ANS X3S35/125).

A new task was undertaken for the USPS during the past year. Its purpose is to plan for the front-end processors (FEP) for the electronic mail system and develop a protocol/interface demonstration and test.

The ITS is developing functional requirements for an electronic mail system FEP. These requirements include system capacity and network interfaces. The amount of system capacity needed will determine if the FEP is minicomputer or microprocessor based and what peripherals are necessary. Common types of networks that may be interfaced are switched terrestrial, private leased lines, value-added networks, and satellites.

The hardware and software necessary for implementing the FEP functional requirements is also being examined. The hardware/software mix to interface the various common carriers and to support anticipated protocols must be determined. Commercially available hardware and software that meet the functional requirements of the FEP are to be identified.

Alternative FEP configurations will be evaluated with respect to protocol support, data throughput, and cost. FEP configurations using off-the-shelf equipment and software packages are preferred.

The second part of this task is the planning and implementation of a protocol/interface demonstration and test. The purpose is to develop, demonstrate, and test many of the concepts and functional requirements developed under the first part of this task. Protocols to be tested will be determined within the framework of the OSI reference model.

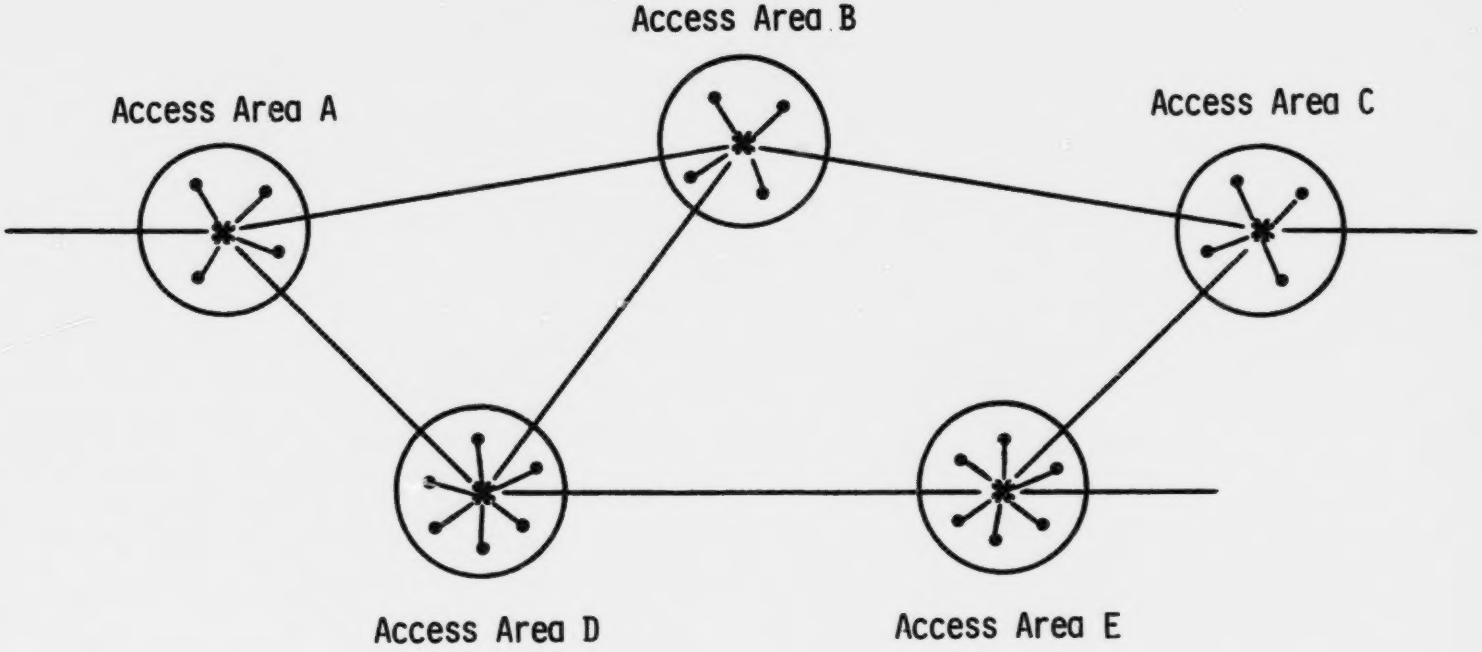
The ITS is developing a demonstration test plan outlining the type of telecommunication link to be used, the interface parameters, the protocols to be evaluated, tests to be conducted, and the test schedule. The telecommunication link may be a commercial packet-switching network or common carrier dial-up facilities. A minimum of the bisynchronous protocol and packet-switching based on the CCITT Recommendation X.25 will be tested. Consideration will also be given to testing the asynchronous type protocol. Communication parameters such as bit- and block-error rates and data throughput will be determined as a part of the tests.

Access Area Digital Switching System (AADSS). The U.S. Army's Communications Systems Agency (CSA) at Ft. Monmouth, New Jersey, is evaluating concepts and alternatives for providing an efficient interface between the future Defense Communications Systems (DCS) AUTOVON network and contiguous military base environments called access areas. The access area concept is illustrated in Figure 4-5. The AUTOVON network consists of 59 switching centers that are interconnected in a polygrid backbone network. Each switch is connected with several other switches. The access area consists of a clustering of military installations in the vicinity of an AUTOVON switch. Trunks carry concentrated traffic from the military installations to the AUTOVON switching centers. The traffic is then routed throughout the AUTOVON backbone network to the destination. Some bases having a high strategic value are multiple-homed on more than one switch.

The Communications Systems Agency has been tasked by the Defense Communications Agency to make recommendations regarding new access area topologies and implementations. The motivating factors for this investigation are: 1) rapidly increasing tariffs which are causing access area costs as well as the costs for the entire AUTOVON network to increase dramatically; 2) the need for enhanced survivability through the use of more endurable topologies; 3) new telecommunications services which are becoming available through the use of advanced technology. In support of the CSA, the Institute has conducted numerous studies related to AADSS program. Previous ITS efforts have included studies on (1) parametric cost alternatives for local digital distribution systems, (2) preliminary evaluation of hub alternatives, (3) an example of the design for a digital time division switch with stored program control, (4) traditional signaling techniques for controlling the switch, (5) a study of new and complex signaling issues which arise in integrated (voice/data) communications networks, (6) an evaluation of switch element capacities in access area digital switching systems, and (7) regional modeling for applying AADSS concepts to an access area in New Jersey. Item 7 above has recently been completed and will be summarized in the following paragraphs.

Figure 4-6 depicts, in a simplified way, several different possible topologies for the access area. The star topology is the topology currently implemented. The tree topology attempts to reduce circuit-miles (and hence costs) through concentration of traffic from limbs onto major branches. The loop and polygrid topologies as seen in Figure 4-6 are other feasible implementations for the access area. Finally there is the AADSS type loop in which the existing AUTOVON switch has been eliminated. The AADSS switch, shown as a shaded block, is either colocated with a base switch or becomes an integral part of the base switch. The AADSS switch in this case must be capable of performing other functions normally handled by the AUTOVON node such as routing control and network management functions. If satellite links are used between such switches, then the AADSS may also perform satellite terminal processing functions as well. The advanced loop topology of Figure 4-6(e) illustrates for long-term goal topology envisioned by the CSA.

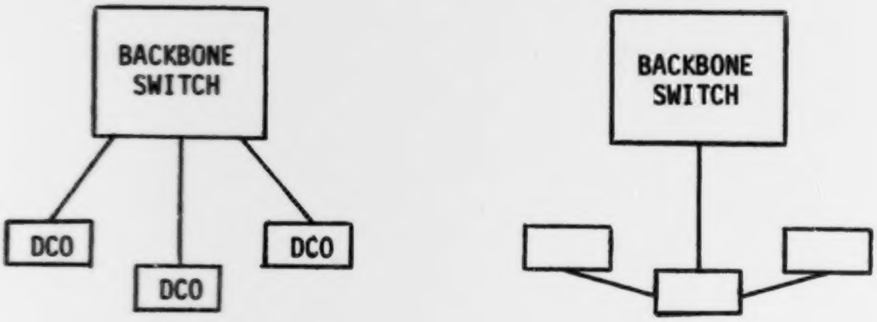
Figure 4-7 depicts the Cedar Brook, New Jersey, access area. Shown in the figure are all of the bases that home on Cedar Brook. The numbers in parentheses indicate the number of trunks between the military installations and the Cedar Brook switch. The ITS has recently completed a study which presents a methodology for evaluating alternatives for


Access Area B
Access Area A
Access Area C
Access Area D
Access Area E

As of June 1980: 59 Nodes
1,060 Subscriber Locations (Average 18 Locations per Node)
15,595 Trunks (Average 260 Trunks per Node)

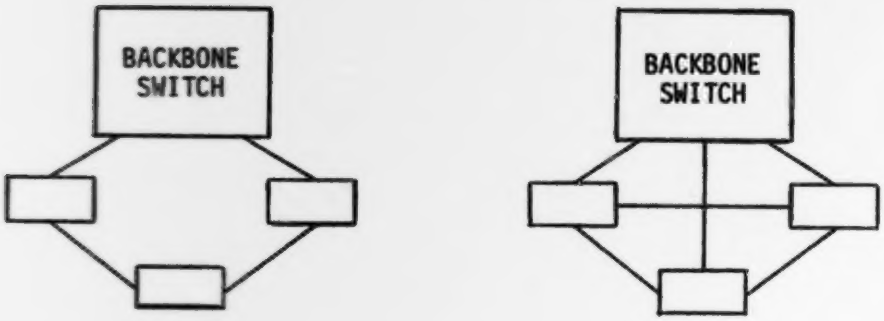
- • Military bases
- ✱ AUTOVON switching centers

Figure 4-5. AUTOVON access area/polygrid concepts.


BACKBONE SWITCH
DCO
DCO
DCO
BACKBONE SWITCH

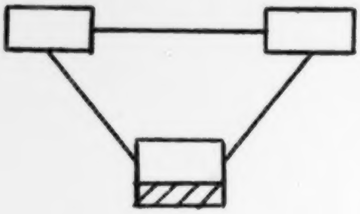
a) STAR

b) TREE


BACKBONE SWITCH
BACKBONE SWITCH

c) LOOP

d) POLYGRID



e) AADSS TYPE LOOP

Figure 4-6. Potential stages for implementing access area networks.

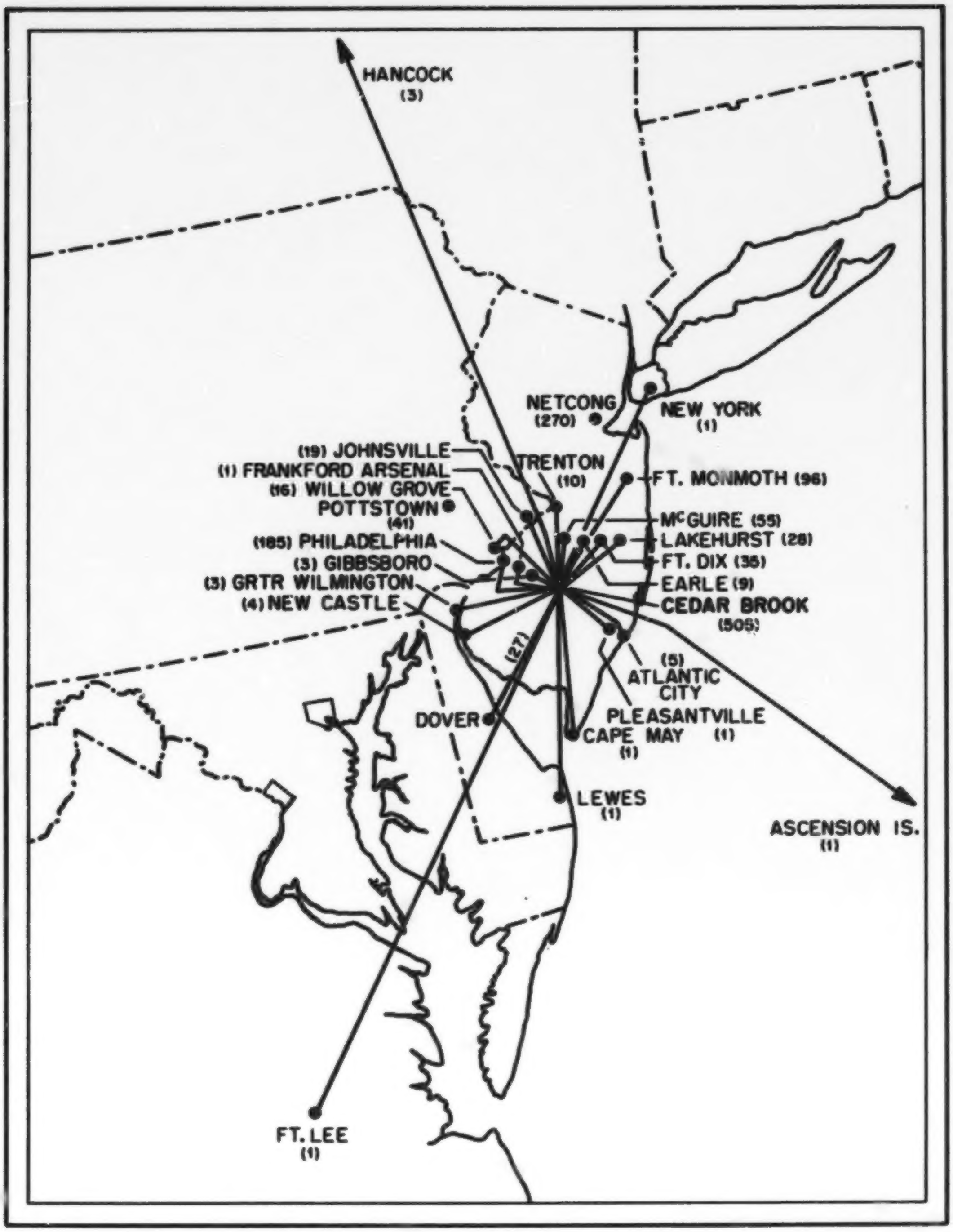

HANCOCK (3)
NETCONG (270)
NEW YORK (1)
(19) JOHNSVILLE
(1) FRANKFORD ARSENAL
(16) WILLOW GROVE
TRENTON (10)
FT. MONMOTH (96)
POTTSTOWN (41)
McGUIRE (55)
(185) PHILADELPHIA
LAKEHURST (28)
(3) GIBBSBORO
FT. DIX (35)
(3) GRTR WILMINGTON
EARLE (9)
(4) NEW CASTLE
CEDAR BROOK (505)
(27)
(5) ATLANTIC CITY
PLEASANTVILLE (1)
DOVER
CAPE MAY (1)
LEWES (1)
ASCENSION IS. (1)
FT. LEE (1)

Figure 4-7. Subscriber locations homing on AUTOVON switch at Cedar Brook, New Jersey.

access areas. As an example of the methodology a thorough analysis of the Cedar Brook access area was made. Different topologies (star, loop, and tree) were investigated as well as different technologies (fiber optics and microwave) and different ownership schemes (private ownership versus leased). It was found that the choice of the access area configuration for the Cedar Brook access area was highly sensitive to cost assumptions for leased line tariffs, fiber optics technology, etc. Under certain assumptions, the current star topology with leased trunks was found to be the least expensive. For a different set of assumptions the use of fiber optic transmission links in a loop topology was found to be the most cost effective.

The important results presented in this study are that a methodology was developed that provides life-cycle costing techniques for both fiber optic and microwave telecommunications systems. Included in the analysis were economic concepts such as the present worth of money, depreciation, amortization, salvage value, and that nemesis to economic stability known as inflation.

Requirements Analysis for the European Defense Communications System. The ITS has recently initiated a study for the U.S. Army Communications Systems Agency which consists of a requirements analysis and network concept development for the European Defense Communications System. An improved European Defense Communications System is required for the following reasons: (1) the need for improved communications survivability in a nuclear environment, (2) the need for increased resistance to enemy sabotage and electronic countermeasures, (3) the need for a better grade-of-service for administrative, logistics, and command-and-control traffic, (4) the need to provide enhanced telecommunications services to meet new class-of-service requirements such as increased usage of facsimile, increased data requirements, and possibly video, and (5) the need for new or enhanced service features some of which are unique to military telecommunications systems such as security, hot-line, and priority pre-emption.

The design and development of a military communications network(s) that meet the needs delineated above involves many complexities. The predominate problem is that of interoperability of numerous military and civil networks. In general, the more interoperability that can be achieved between networks the higher the probability there is that, in a nuclear environment, there will be an operable link between users. It is especially important that connectivity be maintained between critical command-and-control users. Therefore, it is desirable that the United States European Defense Communications System interoperate not only with the military communications systems of the NATO Alliance, but also with the military and civil communications systems of each country in Western Europe. To this complexity, we add the additional problem of interoperability with U.S. tactical communications equipments. All of these systems have features and system parameters that are unique to that particular system.

The goal of the ITS study is to first identify and then address all of the problems related to the interoperability of U.S. and allied communications networks, both military and civil, in Europe. Issues such as digital transmission formats, companding techniques, synchronization, numbering plans, grade-of-service, signaling techniques, radio/multiplexer capabilities, reconstitution in a post-attack environment, secure voice techniques, and user requirements for voice, data, and facsimile are being addressed in this study.

## SECTION 4.3. SATELLITE COMMUNICATION SYSTEMS

The Federal Government has long been committed to satellite communications and to the growth of a vigorous commercial satellite industry for both point-to-point communications and broadcast services. That industry has benefitted greatly from Government-funded R & D efforts, such as those of the Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA), so that today there are well established services for domestic and international large volume, geographically centralized services. However, the services for low volume, geographically dispersed communication have been much slower to develop, and broadcast services are only now being proposed.

Efficient and effective utilization of satellite technology by dispersed, low-volume users (rural areas) can only be realized when significantly lower-cost ground terminals are available. A jointly supported study with the Agency for International Development (AID) to define and encourage industry development of a low-cost, ground terminal system suitable for rural areas and other thin-route satellite communications applications has been initiated. The emphasis of this study has been to define earth station designs and service capabilities through application of a matrix of options for components of the earth station such as the antenna size, the low noise amplifier characteristics, and the high power amplifier characteristics as well as the technology that could be used such as single channel per carrier frequency modulation (SCPC-FM), voice encoding with a digital modulation, and phase-shift-keying such as continuously variable slope delta modulation (CVSD) or adaptive delta modulation (ADM) with quadrature phase-shift-keying (QPSK), or voice synthesis such as linear predictive coding (LPC) with QPSK.

The 1979 World Administrative Radio Conference (WARC) of the International Telecommunication Union (ITU) established frequency allocations for broadcasting-satellite service (BSS) and resolved that a Regional Administrative Radio Conference (RARC) be convened in 1983 for planning broadcasting-satellite service in ITU Region 2 (North, Central, and South America and Greenland). The 1983 RARC for Region 2 must resolve the issues of sharing the Direct Broadcast Satellite (DBS) orbit and radio spectrum between 12.1 and 12.7 GHz. This conference will address the orbit and spectrum sharing issues and requirements of the countries in Region 2. The conference output can produce a very negative environment for the United States (U.S.) DBS industry unless

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favorable planning is accomplished. This can only be done if a strong case for the U.S. position is prepared in advance. Technical studies have been conducted (and will continue) to assist in determining the orbit-spectrum capacity and how it might be shared with the other countries in Region 2.

On December 17, 1980, COMSAT's Satellite Television Corporation (STC) filed the first application with the Federal Communications Commission (FCC) requesting a permit to construct the first phase of an experimental DBS system for delivery of subscription television to homes. By July 16, 1981, when the FCC closed the interim DBS period, fourteen applications had been submitted which presented, in varying detail, a wide range of service concepts. During the past year, ITS gave technical study to the STC application and similar study of other applications is expected to continue. It is important to formulate a U.S. position prior to the 1983 RARC with regard to DBS service in the United States.

The 1979 WARC also resolved to convene another WARC in 1984 to decide which frequency bands for space services (primarily the fixed-satellite service, FSS) should be planned and to draw up a detailed plan for each of these frequency bands. The outcome from the 1983 RARC and the 1984 WARC will have major impacts on efficient use of the frequency and orbit resources by the United States.

The ITS Satellite Communications System Program was comprised of four, NTIA-sponsored projects plus a complementary project sponspored by the Agency for International Development, Department of State, mentioned earlier. These five projects, established for management tractability were: 1) "Frequency/Orbit Resource Study," 2) "Broadcasting-Satellite Service Policy Studies," 3) "Direct Broadcast Satellite and Fixed Service Sharing Studies," 4) "Voice Circuit Multiplier Techniques Study," and 5) "Support to the AID Rural Satellite Program."

### 4.3.1. Frequency/Orbit Resource Study

As noted earlier, the 1979 WARC resolved that a Regional Administrative Radio Conference for the planning of the broadcasting-satellite service (RARC-BS) of the ITU Region 2 be convened in 1983. At this conference, a detailed frequency allotment and orbital positions plan will be drawn up for Region 2. The 1979 WARC also resolved to convene another WARC in 1984 to decide which frequency bands for space services should be planned and to draw up a detailed plan for each of the frequency bands. The outcome from these two conferences will have major impacts on efficient use of the frequency-orbit resources by the United States.

In this fiscal year, efforts have been made towards preparation of the U.S. position for the 1983 RARC-BS of Region 2. The ITS efforts have been made through participation in and contribution to the U. S. National Committee for CCIR (International Radio Consultative Committee) (Joint Working Group 10/11S and Interim Working Party 10-11/2, in particular), IRAC (Interdepartmental Radio Advisory Committee) Ad Hoc 177, and FCC Advisory Committee on the 1983 RARC-BS established under the FCC General Docket No. 80-398.

The SOUP (Spectrum-Orbit Utilization Program) of ORI, Inc., improved under the ITS contract last fiscal year, has been further improved by the ITS in this fiscal year. The improvement includes conversion to the ANSI (American National Standards Institute) Standard Fortran for portability, reduction of storage area, elimination of duplicated calculations for common uplinks, adaptation to the 1977 WARC-BS specification of a satellite antenna, etc. Documentation of SOUP with sample runs is under way.

The 1977 WARC-BS decided to use elliptical beams for satellite transmitting antennas in the broadcasting-satellite service for the planning purposes. A method for minimizing the area (or solid angle) of the ellipse for a given service area and an orbital position has been developed and implemented in a computer program. This method is about ten times faster than the other method used so far elsewhere in the United States.

### 4.3.2. Broadcasting-Satellite Service Policy Studies

The ITS provided comments and summarizations of other respondents' comments to FCC Notice of Inquiry (NOI) Docket No. 80-398 and Docket No. 80-603. The NOI Docket No. 80-398 is an inquiry relating to preparations for the 1983 Region 2 RARC for planning of the broadcasting-satellite service in North, Central and South America and Greenland in the band 12.1 and 12.7 GHz and associated uplinks. This preparation must include consideration of criteria for sharing between the BSS and the terrestrial microwave Fixed Service (FS) users.

Comments requested by the Commission in the NOI included the following items:

- basic service requirements,
- division and allocation of the 12.1-12.3 GHz bands,
- technical specifications and sharing criteria and planning principles, i.e., orbital placements, frequency and channel allocations, etc., and
- a U. S. Advisory Committee.

Responses by the ITS to Docket No. 80-398 were both in direct reply to the Inquiry and summaries of the large number of comments and reply comments that came from interested parties -- terrestrial microwave operators who felt a potential threat to their use of the 12 GHz band, the networks who felt that DBS would be a threat to services already being provided by the broadcasters, and, of course, those who viewed DBS as a potentially attractive satellite service to meet their own requirements as service providers or as service users.

Three documents were prepared in ITS reviewing comments and reply comments. The first two documents were made part of the agenda of IRAC 177-1.

- "A Synopsis of Comments to FCC-NOI Docket No. 80-398, Planning for 1983 RARC for 12 GHz Broadcast Satellite Services, February, 1981.
- "Memorandum - Issues Relating to U. S. Positions on 83 RARC," February 26, 1981.
- "A Synopsis of Reply Comments to the FCC NOI Docket No. 80-398, Planning for the 1983 RARC for 12 GHz Broadcast Satellite Services," March, 1981.

A set of matrices citing organizations' reactions to the NOI was prepared and presented in the Synopses of Comments. It is to be noted that at the time of the Inquiry (Released July 25, 1980) and into the fall and winter, 1980, there were almost no organizations other than the Satellite Telecommunications Corporation, a subsidiary of COMSAT, who felt DBS a service worth pursuing. Only STC had applied by the spring of 1981 for a DBS satellite service. However, a total of 14 applications had been filed with the FCC by the deadline date, July 16, 1981, requesting interim licenses to operate or broadcast on DBS. Applications also included filings from a variety of unknown organizations established perhaps just for this service as well as a number of principals in the broadcast, equipment, or satellite fields; e.g., CBS, Western Union, RCA, STC, etc.

Satellite Television Corporation, in their application to provide DBS services, offered their proposal to operate a number of channels from each of four satellites strategically placed in orbital position to cover approximately each time zone throughout the contiguous 48 states. Spot beams from the DBS satellite would be directed toward Alaska and Hawaii to meet their service needs. STC detailed an approach to orbital placements of satellites and offered a number of recommendations for shaping the radiated power beam to achieve uniform signal density in the reception areas. STC recommended a clear split of the 12.1-12.3 GHz sub-band rather than a sharing of such frequencies with the FSS. The STC reaction to the questions of potential interference of fixed terrestrial services with DBS is that a shift of the FS frequencies within the band should, in most cases, alleviate the problems of interference.

Most respondents to the NOI No. 80-398 may be grouped into categories such as commercial TV broadcasters, public service organizations, suppliers of equipment and/or public/private telecommunication services via terrestrial microwaves or satellite, and the user communities for the latter services. A digest of the reactions to DBS services by some of the special interest groups follows.

The commercial TV broadcasters, the broadcasting associations, and the TV networks look upon broadcast satellite services and, in particular, direct-to-home satellite TV either as an unnecessary additional attempt to provide pay TV or as a potential threat to the commercial TV services already well established throughout the United States. DBS services would place, in the hands of a small number of (national) TV operators, a TV broadcasting medium and service that would compete with locally operated TV stations on a time, service, and available talent basis. The recommendations from the broadcasters are that the services or uses of BSS be non-competitive with commercial TV and preferably directed towards community public service and educational needs rather than entertainment.

Private users or suppliers of the terrestrial microwave telecommunication services such as the utilities, petroleum companies, and railroads express in their comments to the Commission a common concern -- "What will be the effect upon their fixed (or in some cases, fixed satellite) services as the result of an extensive BSS?" They argue that there are long-term requirements for a highly viable telecommunication system to meet the needs of the U.S. public as well as their own special or private communications.

The public service associations and consortiums look upon broadcast satellite services as a means for efficient telecommunication dissemination of essential educational, social, government, health, public interest, and information services. They recommend community reception in preference to direct-to-home reception, and encourage a diversity of video services to allow for maximum dissemination of information.

All parties who commented to the FCC NOI No. 80-398 were in favor of an Advisory Committee to help in the planning process for the establishment of a U.S. position at the 1983 RARC.

In addition, the ITS cooperated with the Office of Policy Analysis (OPAD), another component of the NTIA, in preparing the NTIA comments responding to FCC General Docket No. 80-603, an inquiry into the development of regulatory policy in regard to Direct Broadcast Satellites for the period following the 1983 Regional Administrative Radio Conference. These comments were filed with the FCC on April 15, 1981. The NTIA filing became one of the main driving forces for the FCC's decision to accept applications for interim DBS systems for filing at this time (i.e., before the 1983 RARC-BS for Region 2).

The Technical Summary of the NTIA Comments urged the Commission to consider the following technical recommendations:

1. Adopt interim procedures for authorizing DBS services prior to the 1983 Regional Administrative Radio Conference (RARC) to facilitate U.S. preparations for RARC-83 and to reduce service delays in the post-1983 period.
2. Grant applications in a timely manner by issuing conditional construction permits which will allow initial procurement activities, but not launch or operation,

prior to RARC-83. However, do not assign orbit positions and frequencies until after RARC-83.

3. Adopt technically flexible orbit spectrum utilization policies for the emerging domestic DBS market, but do not implement the Staff Policy Report* recommendation of contiguous spectrum block assignments.

4. Resolve the FS and BSS sharing problem in the 12.2-12.7 GHz band by sharing within the band, extending the FS band, encouraging an FS move to a higher band (18 GHz), or a combination thereof.

5. If sharing within the band is adopted as a short-term solution to FS-BSS interference, establish a policy of prior (or incumbent) spectrum use rights for all licensees in the 12.2-12.7 GHz band and allow DBS operators to compensate FS users for modifications.

### 4.3.3. Direct Broadcast Satellite Fixed Services Sharing Studies

The broadcast band between 12.2 to 12.7 GHz within the United States is allocated for the transmission of commercial television from a direct broadcast satellite (DBS); for private, safety, industrial, and transportation (PSIT) fixed terrestrial microwave; and for commercial high resolution television. This program is an expanded analysis of the technical sharing issues between the DBS and the PSIT fixed terrestrial microwave systems. This assumes that both systems will operate within this band as opposed to moving either one or the other system out to a different frequency band. There are two options for interference within this band between these two systems: the DBS signals interferring with the terrestrial microwave and the fixed terrestrial microwave interferring with the reception of the DBS home receivers. The DBS home receivers are assumed to use inexpensive parabolic dishes which are generally less than 1-meter in diameter.

Figure 4-8 shows a typical home receiver mounted on a dwelling.

It was concluded early in this study that the interference is basically from the fixed terrestrial microwave transmitters to the DBS home antenna and receiver systems. The focus, therefore, is on the proliferated terrestrial microwave transmitters in the U.S. which can potentially interfere with the home receivers of the DBS.

There are approximately 1500 operational microwave transmitters in the U.S. with another 870 known systems in various stages of planning and installation. Almost all of these microwave systems support local distribution as opposed to long-haul use. This compounds the sharing issue since the use of these microwave systems are almost proportional to population centers. One of the worst-case centers is Los Angeles. A plot of the fixed terrestrial microwave systems in Los Angeles is shown in Figure 4-9. It is clear from such a map that the potential for interference from microwave transmitters to home receivers in the Los Angeles metropolitan area is a technical concern.

This study has shown a "no control of restriction" approach is technically absolute worst-case for all parties. There are several options. One is to split or interweave the bands of operation of both systems by compacting the PSIT microwave users and inserting DBS into the remaining frequency band or bands. Compacting the PSIT microwave user technically requires combinations of reducing transmitter power, increasing the size of selected microwave dish diameters, and reconfiguring selected networks. Fortunately, the compaction problem currently manifests itself in only a half dozen or so of the larger metropolitan areas. Technically, the relocation of microwave users in smaller centers is greatly simplified since there is sufficient unassigned bandwidth in 12.2 to 12.7 GHz. Our analysis does indicate, however, that the total use of PSIT microwave is increasing at an annual rate of 10 to 20% compounded. The process of sharing, therefore, becomes more technically elegant with each passing year.

Our study restricted the size of the home-terminal receiver dish to 1-meter or less. Increasing the dish size causes major increases to the consumer -- a boundary condition placed on the analysis.

Some exploratory measurements of interference from FDM/FM common carrier signals to TV signals from SATCOM I in the 4 GHz band were made at five locations in the Boulder area. These measurements were done to determine the nature of the interference environment in which 4 GHz, receive-only, satellite earth stations operate at present.

The measurements were made using a leased, receive-only, transportable satellite terminal to which a spectrum analyzer, strip recorder, and a TV monitor were added (see Figure 4-10). The leased terminal consisted of a 10-foot antenna, polarization selector, low noise amplifier, and (rf) receiver.

Our measurements, which must be regarded as producing preliminary results, show that adjacent to a receive-only terminal used to feed a local cable TV network, carrier-to-interference ratios, C/I, of between 30 and 45 dB were measured which did result in degraded reception determined subjectively by observation of the TV monitor, though there is not a one-to-one correspondence between C/I and picture quality.

Although the primary interest is for information relating to the planning of DBS services in the 11-12 GHz band, it was felt, in the absence of DBS signals, that data obtained at 4 GHz would be relevant insofar as protection requirements are concerned. It should be noted that Section 4.1.2 of CCIR Doc. 10/11S/87 Rev. 1 quotes the need for protection ratios of 35 and 32 dB for interference between NTSC-

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*Staff Report on Policies for Regulation of Direct Broadcast Satellites, FCC Office of Plans and Policy, September, 1980, by F.O. Setger, B.A. Franca, and N.W. Cornell.

Figure 4-8. Typical home receiver dish for DBS.

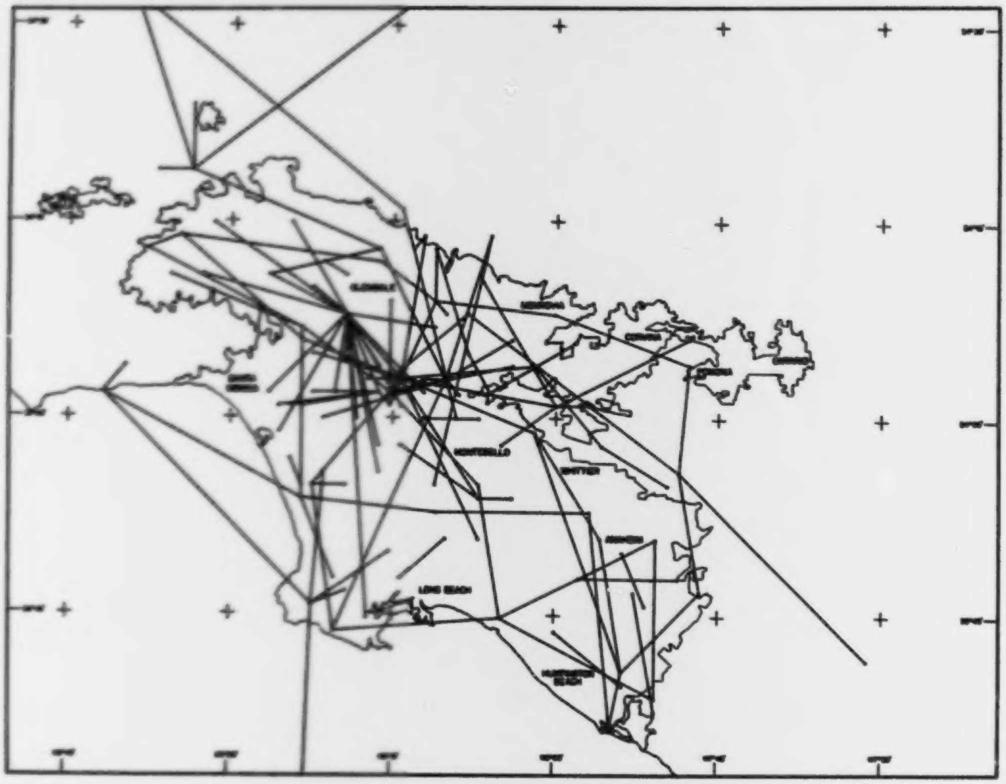
GLENDALE
MONTEBELLO
WHITTIER
ANAHEIM
LONG BEACH
HUNTINGTON BEACH

Figure 4-9. Fixed terrestrial microwave paths at 12.2-12.7 GHz in the greater Los Angeles area.

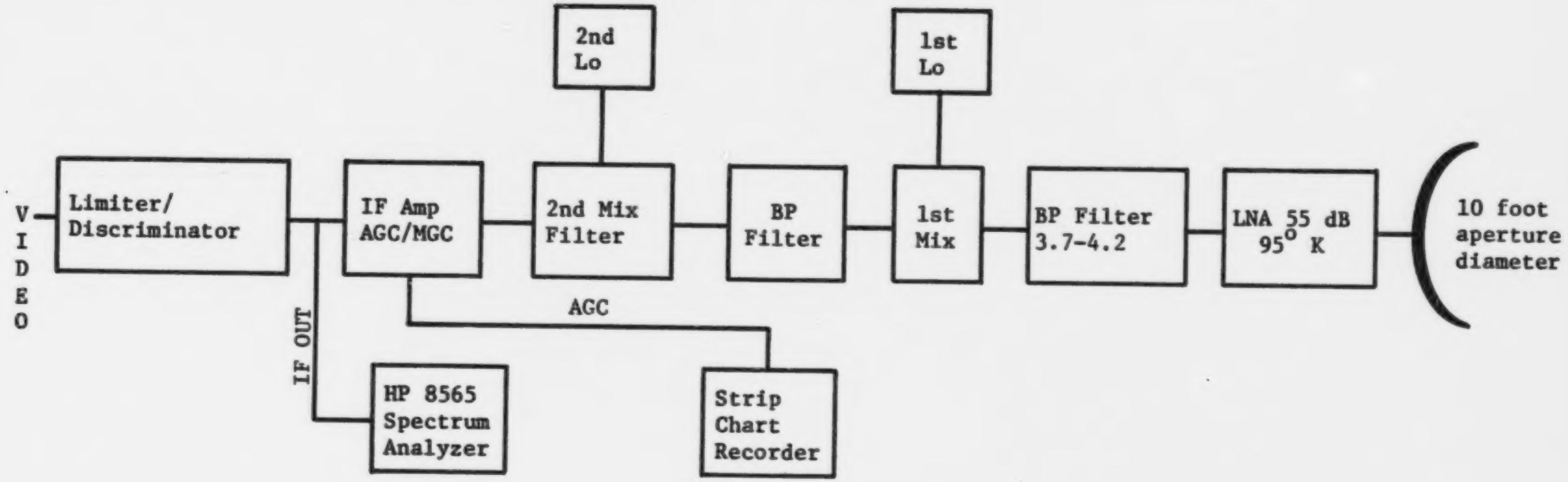
2nd
Lo
1st
Lo
V I D E O
Limiter/
Discriminator
IF Amp
AGC/MGC
2nd Mix
Filter
BP
Filter
1st
Mix
BP Filter
3.7-4.2
LNA 55 dB
$95^{o}$ K
10 foot
aperture
diameter
AGC
IF OUT
HP 8565
Spectrum
Analyzer
Strip
Chart
Recorder

Figure 4-10. Block diagram of instrumentation for carrier-to-interference ratio measurements at 4 GHz.

TV and FDM/FM telephony signals loaded at 60 and 970 channels, respectively.

### 4.3.4. Voice Circuit Multiplier Techniques Study

This study is being done for the NTIA International Affairs Office. With the formation of INTELSAT in 1964-65, geosynchronous satellites have grown to be the dominant, long-haul, transoceanic, telecommunications transmission medium. Since 1973, similar satellites are being increasingly employed for domestic networks. Throughout all this period, the technology of communications and of satellites has expanded enormously and new techniques, including components, modulation formats, spot beams, frequency reuse, and a host of circuit multiplier ideas, have been brought forward. Because of increasing frequency and geosynchronous orbit congestion and the further growth in size and scope of satellite systems, methods of improving the spectrum efficiency of these systems are of great importance.

The objectives of the study are to investigate various signal formats and processing techniques for improving the efficiency of voice communications by satellite. In particular, a common base comparison is being developed between analog and digital, between FDMA and TDMA, and between modulation efficient schemes such as QASK and Source Coding (bit rate reduction), schemes such as Adaptive Delta Modulation (ADM) and Linear Predictive Coding (LPC), etc. These comparisons with baseline systems allow assessments of their relative merits for satellite usage.

Three baseline systems for voice service based on the INTELSAT channelization and signal structure have been selected. These are (1) the frequency division multiplex, frequency modulation, frequency division-multiple access (FDM/FM/FDMA) analog format commonly used by INTELSAT; (2) the time division multiplex, time division-multiple access, digital speech interpolation (TDM/TDMA/DSI) digital format which is now being implemented by INTELSAT at earth stations with very large volumes of traffic; and (3) the pulse code modulation, quadrature phase shift keyed, single channel per carrier (PCM/QPSK/SCPC) format.

Techniques being evaluated relative to these baseline systems include:

a) analog companders employing microcircuits;
b) digitization source encoding such as Delta Modulation types (ADM and CVSD);
   linear predictive coding (LPC) and adaptive/predictive coding;
c) efficient (alternative) digital modulation techniques such as QPSK, MSK, QPR, 16-PSK, and 16-ASK;
d) other circuit multiplier techniques such as time averaged speech interpolation (TASI), digital speech interpolation (DSI), etc.; and
e) selected combinations of above techniques.

The need and effect of error correction coding in the use of digital techniques are also a part of the study which is expected to be completed early next fiscal year.

### 4.3.5. Support to the AID Rural Satellite Program

The Rural Satellite Program, established by the Agency for International Development, is a five-year, cooperative effort between the United States and a number of developing nations to develop and demonstrate the value of communications technology, particularly as realized through use of communication satellites, upon development efforts of less-developed nations. The establishment of reliable communications systems into rural areas of the developing nations provides an important and essential capability which can be used to improve methods of producing and availability of food, to improve health and family planning services, to stimulate productive work, and to provide access to education.

This was the second year of technical support by the Institute to the Rural Satellite Program. Support during the past year provided assessments of various proposals made to the Agency for International Development as useful to the Rural Satellite Program.

One proposal was for "intelligent" earth stations employing time-division, multiple-access technology, and compatible, packet radio communication systems for terrestrial, local distribution of service into an area surrounding an earth station. The earth terminal is designed to provide multiple access data transmission and digital voice communications employing time-division multiplex (TDM) and time-division, multiple-access (TDMA) with quadrature phase-shift keying (QPSK) for rf modulation at rates from 268.8 kb/s to 2.048 Mb/s. Voice encoding is accomplished using continuously-variable slope delta modulation (CVSD) operating at 32 kb/s. These terminals could be networked as either star or mesh networks operating with an INTELSAT satellite using antennas with apertures of 7 to 10 m, depending upon the selected network concept and available space segment. Following a star network concept, a Rural Satellite Program application could realize service using continuous broadcast transmission and TDM technology for communication from a central location to a number of "remote" earth stations. Return communication from the remote sites could employ TDMA bursts. The technology for these systems is near the leading edge for fielded, satellite communication service, therefore quite expensive -- probably near or exceeding $100,000 per earth terminal.

The second proposal was for earth stations providing limited voice communication capability as a supplemental service to television receive-only service. This service concept depends upon an existing capability for originating at least one channel of television programming which is distributed via satellite. The concept dictates a star network. Radiotelephone service from the central station to remote terminals would be provided as digitized voice signals (maximum of about 10), modulated as a subcarrier on the television signal between the chromatic subcarrier and the

(TV) audio subcarrier. Return communication from the remote terminals would occur as very low-power carriers (up to about 10 maximum for simultaneous operation) near the transponder band edge. Antennas with apertures of 4.5 m could be used for the remote terminals. Also, other cost-reducing techniques for frequency translation from baseband to radio frequencies and back to baseband were proposed. Delta modulation was proposed for voice signal encoding. The projected earth terminal cost was about $35,000 to $50,000; however, many proposed techniques involved unproven technology and production methods. Furthermore, a capability for radio telephone (and limited data transmission) dependent upon existing origination and distribution by satellite of television programming does not correspond to the perceived "typical application" that will be made in the Rural Satellite Program.

The third proposal was for development of "low-priced" television technology, with emphasis directed to development of a low-priced television receiver. This is a proposal to provide single channel service using special broadcast techniques to reduce the transmission bandwidth. These techniques would include line averaging to reduce the number of scan lines per frame, interlace scanning, and antimation emphasis. The receiver would be suitable only for subdued light viewing and would incorporate features which would allow manufacturing of the receivers within a developing country at a targeted cost of about $5.00 U.S. Features of the receiver include:

a) A long, round-face (5 to 7 inches in diameter) picture tube that could be manufactured using incandescent light bulb technology.

b) An electron gun assembly that would be produced separately on a glass button in a glass neck that could be joined to the picture tube "bottle" using "sealex" machines.

c) Low beam acceleration voltage (1000 to 2000 V rather than 25,000 V typical of current technology) and electrostatic beam deflection rather than electromagnetic, thus avoiding the expense of the cooper wire, beam deflection coil.

d) Primary power would be provided by a rechargeable battery not included in the estimated cost above.

The proposal has merit for helping to realize Rural Satellite Program objectives of providing educational information and improved health and family planning service to rural areas of less developed countries.

Finally, we have taken a unique approach to the problem of defining system design characteristics and service features for a small, low-cost, earth terminal for Rural Satellite Program applications. Only general definition of service requirements for "typical" pilot project applications have been provided. Therefore, we are following a parametric, matrix plan in establishing service that can be provided by several prospective technologies, mentioned in the introduction for this section. The following assumptions and component parameter values are being used in the design analysis:

a) Typical applications will be considered initially to be star networks of remote earth terminals operating with a central earth terminal which is INTELSAT Standard B or equivalent in G/T capability. The number of remote earth terminals per network is a parameter of the analysis.

b) Space segment service for the network will be provided by leased INTELSAT transponder with either global or hemispherical beam coverages, regional satellite (i.e., PALAPA) transponder, or domestic satellite (i.e., WESTAR or SATCOM) transponder.

c) Earth terminal antennas are assumed with aperture diameters of 3.0 m, 4.5 m, 6.0 m, 8.0 m, and 10.0 m.

d) Earth terminal receiving systems are assumed to incorporate a low noise amplifier with an operating temperature of 55°K, 90°K, 120°K, 150°K, or 200°K.

e) The conditions of (c) and (d) above provide earth terminals with G/T ranging from 16.3 dB/°K to 30.9 dB/°K.

f) Telephony service will be provided using companded FM, SCPC technology, digitally encoded voice (i.e., CVSD or ADM) with QPSK modulation technology, or synthesized voice (i.e., LPC) with QPSK modulation technology.

g) Service capacity that can be supported by a quarter transponder with combinations of technologies and earth terminal characteristics identified above is being determined.

As an example of the study results being developed and how these results will be used, Figure 4-11 is a family of curves, parametric in G/T, relating numbers of telephone channels that can be provided versus the amount of satellite power that is required. The assumed conditions are 1/4 transponder of an INTELSAT satellite operating with hemispherical beam coverage using digital technology at 9.6 kb/s with bit error rate of $10^{-4}$ and QPSK modulation. Operation would be in a star network with an INTELSAT Standard B central terminal. The figure shows that maximum power available for 1/4 transponder on an INTELSAT satellite using hemispherical coverage is 14 dBW or about 25 W. If an application required 50 voice circuits, the remote-to-central channels would be provided by the combinations of remote terminal G/T capability and associated satellite power consumption shown in Table 4-1.

We see that it would be impossible to provide the required service with a remote earth

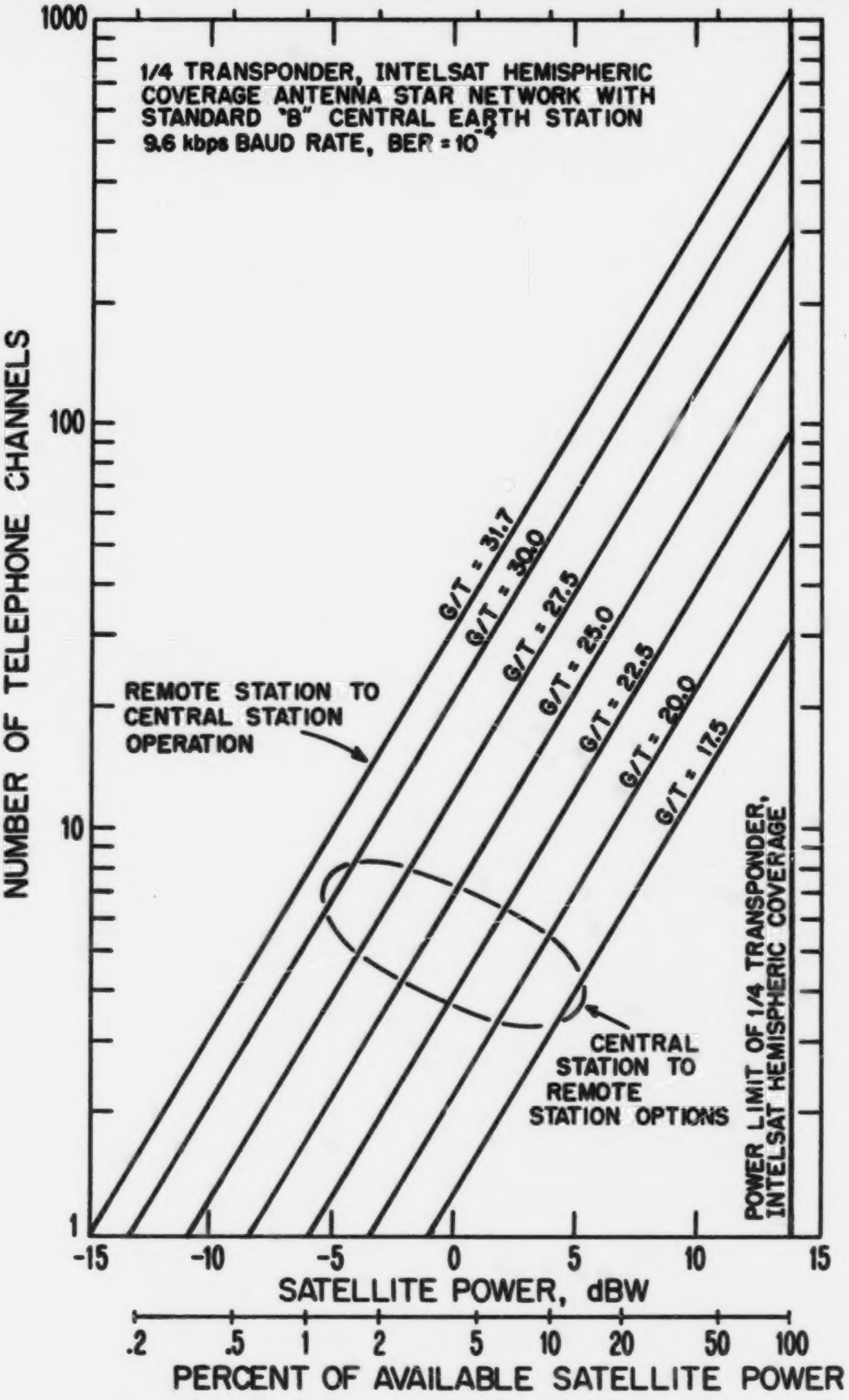

Figure 4-11. Satellite power required vs. number of telephone channels, parametric in G/T of the receiving earth terminal.

terminal for which the G/T is 17.5 dB/°K, since required power exceeds the available satellite power for 1/4 transponder. Several options remain, however, from which a selection can be made which will be influenced by a variety of additional considerations. The information presented in Figure 4-12 helps in making those decisions. Let's assume that we will provide the 50 duplex circuits using a remote terminal with G/T=22.5 dB/°K. This option will consume about 56.5% (50.1%+6.4%) of the satellite power available from the 1/4 transponder of an INTELSAT satellite operating for hemispherical coverage. Figure 4-12 then shows that the receiving system can be a 4.5-m antenna and low-noise amplifier for operation at 90°K or a 6.0-m antenna and low-noise amplifier for operation at about 195°K. The cost trade-offs of these options will guide the selection.

This study, published as a technical report, will be completed early next fiscal year.

Table 4-1. Satellite Power Required to Provide Fifty Duplex Telephone Circuits Using Digital Voice Encoding at 9.6 kb/s and QPSK Modulation, an INTELSAT Standard B Central Earth Station, Remote Earth Stations with G/T Ranging from 17.5 to 30 dB/°K, and One-Quarter Transponder on an INTELSAT Satellite with Hemispheric Beam Coverage

| G/T (dB/°K) | Remote-to-Central Required Satellite Power W | Remote-to-Central Required Satellite Power dBW | Central-to-Remote Required Satellite Power W | Central-to-Remote Required Satellite Power dBW | Percent of Available Power, 1/4 Transponder |
|---|---|---|---|---|---|
| 17.5 | 39.5 | 16.0 | Does not apply. | | >100 |
| 20.0 | 22.3 | 13.5 | Does not apply. | | 88.7 |
| 22.5 | 12.6 | 11.0 | Does not apply. | | 50.1 |
| 25.0 | 7.1 | 8.5 | Does not apply. | | 28.4 |
| 27.5 | 4.1 | 6.1 | Does not apply. | | 16.2 |
| 30.0 | 2.3 | 3.7 | Does not apply. | | 9.3 |
| 31.7 (Std. B) | Does not apply. | | 1.6 | 2.6 | 6.4 |

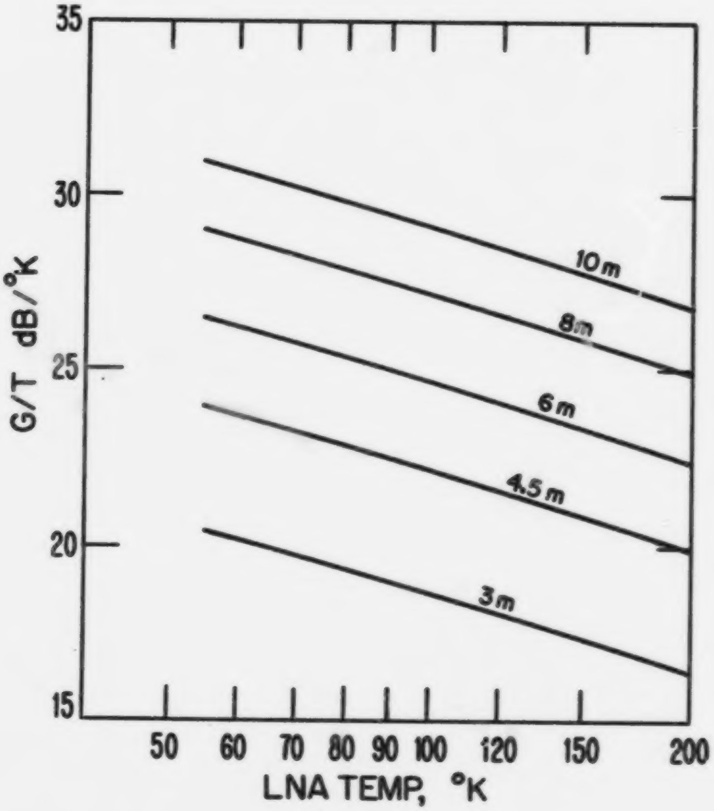

Figure 4-12. Earth terminal G/T as a function of low noise amplifier temperature, parametric with antenna aperture diameter.

# ANNEX I
# ORGANIZATIONAL DIRECTORY
# INSTITUTE FOR TELECOMMUNICATION SCIENCES

NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, DEPARTMENT OF COMMERCE
325 Broadway, Boulder, Colorado 80303
(303) 497 + extension (PTS dial 320 + extension)

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| WALTERS, William D. - Budget and Accounting Officer | 5414 | 3019 |
| STONER, Russell B. - Publications and Technical Information Officer | 3572 | 3009 |
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# ANNEX II
# ITS PROJECTS FOR FY 81
# ORGANIZED BY DEPARTMENT AND AGENCY

| Project | Title | Leader |
|---|---|---|
| COMMERCE, DEPARTMENT OF | | |
| | Maritime Administration (MARAD) | |
| 9102419 | MARAD Assistance | deHaas |
| | National Oceanic and Atmospheric Administration (NOAA) | |
| 9104452 | NOAA-Weather Service Telecommunications Study | Farrow |
| | National Telecommunications and Information Administration (NTIA) | |
| 9100110 | Region 2 MF Conference | Washburn |
| 9100120 | HF Broadcast WARC | Lucas |
| 9101120 | UHF Comparability | Adams |
| 9101122 | UHF Frequency Assignment Status | Hale |
| 9101123 | Tradeoffs for Efficient Use of the Spectrum | Berry |
| 9101124 | Expanded FM Capacity | Adams |
| 9103100 | Undersea Cable/Satellite Trade-Offs | Hull |
| 9104120 | Data Communication Systems Performance Standards | Seitz |
| 9104121 | Guided Wave Communications | Hull |
| 9104122 | Montana/Utah Communications Architectura | Gates |
| 9104140 | Broadcasting Satellite Systems 83 RARC | Jennings |
| 9104141 | Policy Technical Support | Jennings |
| 9104142 | Direct Broadcast Satellite | Jennings |
| 9104143 | TV Receiver-Interface Standards for Information | Bloom |
| 9104144 | Circuit Multiplier Study | Jennings |
| 9105100 | Boundary Studies | Thompson |
| 9105101 | Standards | Pietrasiewicz |
| 9105102 | Terminal Evaluations | Pomper |
| 9105103 | Common Carrier | Pietrasiewicz |
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# ANNEX V

## GENERAL AND HISTORICAL INFORMATION OF ITS

The Institute for Telecommunication Sciences (ITS), largest component of the National Telecommunications and Information Administration, is located at the Boulder Laboratories of the Department of Commerce and has (as of Sept. 30, 1981) a full-time permanent staff of 90 and other staff of 22. In FY 198, its support consisted of $4.1 million of direct funding from Commerce and $5.0 million in work sponsored by other Federal agencies.

The Boulder Laboratories include research and engineering components of the National Bureau of Standards, the National Oceanic and Atmospheric Administration, and the National Telecommunications and Information Administration. Common administrative services are the rule in the Boulder Laboratories. The Radio Building, which houses ITS, is on the U.S. Department of Commerce campus at 325 Broadway. In addition to ITS, the National Telecommunications and Information Administration also has its Boulder Division of the Office of Policy Analysis and Development located in the 30th Street Building off Baseline Road in Boulder.

The following brief history shows the Institute's beginnings. The Radio Section of the National Bureau of Standards was founded prior to World War I and played a major role in the evolution of our understanding of radio propagation. Dr. J. H. Dellinger, its director for most of the period up until World War II, was strongly convinced of the importance of research and gave it practical application as first chairman of the Study Group on Ionosphere Propagation in the CCIR.

During World War II, the Interservice Radio Propagation Laboratory (IRPL) was organized at the National Bureau of Standards, under the direction of Dr. Dellinger. His group provided a common focus for military needs in propagation during the war. In 1946, the Central Radio Propagation Laboratory (CRPL) was established, and in its early years had direct ties with the Defense Department; for example, senior officials of DoD would appear before Congress to defend the CRPL budget. In 1949, Congressional concern for the vulnerability of Government laboratories located in Washington, DC, and the crowding of the NBS Connecticut Avenue campus made it advisable for the radio research work to be taken elsewhere.

Three sites, one in California, one in Colorado, and one in Illinois, were considered, and Boulder, Colorado, was selected. The first group from CRPL, which at that time included radio standards work, moved to Colorado in 1951, and the move was completed in 1954, during which year President Eisenhower dedicated the NBS Radio Building. The Radio Standards program left CRPL at the time of the move to Boulder, and has pursued a parallel existence at Boulder in NBS since that time.

In 1954, CRPL consisted of two research divisions: Radio Propagation Physics and Radio Propagation Engineering. The Radio Systems Division was formed in 1959. In 1960, the Upper Atmosphere and Space Physics Division and the Ionosphere Research and Propagation Division were formed from the Radio Propagation Physics Division. In 1962, CRPL received a full-time director, Dr. C. Gordon Little. In 1965, Dr. H. Herbert Holloman, first Assistant Secretary for Science and Technology in Commerce, implemented a decision to unify geophysics in Commerce with the creation of the Environmental Science Services Administration (ESSA), made up of the Weather Bureau, the Coast and Geodetic Survey, and the Central Radio Propagation Laboratory. At that time, the CRPL was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, the Institute for Telecommunication Sciences came into being. It contained the telecommunications-oriented activities of ITSA. Dr. E. K. Smith served as an interim director for one year and was followed by R. C. Kirby who was director for the ensuing three years.

Meanwhile, in Washington, major attention was being given to the organization of telecommunications in the Federal establishment, and the Department of Commerce established an Office of Telecommunications in 1967. Reorganization Plan No. 1 of 1970 and Executive Order 11556 established the Office of Telecommunications Policy (OTP) in the Executive Office of the President, and assigned additional responsibilities to the Secretary of Commerce in support of OTP. To meet these responsibilities, the Office of Telecommunications (OT) was given expanded responsibilities on September 20, 1970, and ITS, along with its programs, property, personnel, and fiscal resources, was transferred to OT.

In 1971, Douglass D. Crombie became director of ITS. ITS has shifted from its strong emphasis on radio wave propagation and antennas since 1970 in the direction of applications in spectrum management and in telecommunication systems.

In March 1978, President Carter signed Executive Order 12046 which established the National Telecommunications and Information Administration and merged some of the functions of the Office of Telecommunications Policy with those of the Office of Telecommunications in the new agency. ITS was assigned the responsibility of managing the telecommunications technology research programs of NTIA and providing research support to other elements of NTIA as well as other agencies on a reimbursable basis. Among other assigned tasks, the Institute was to remain "...the central Federal Government laboratories for research on transmission of radio waves."

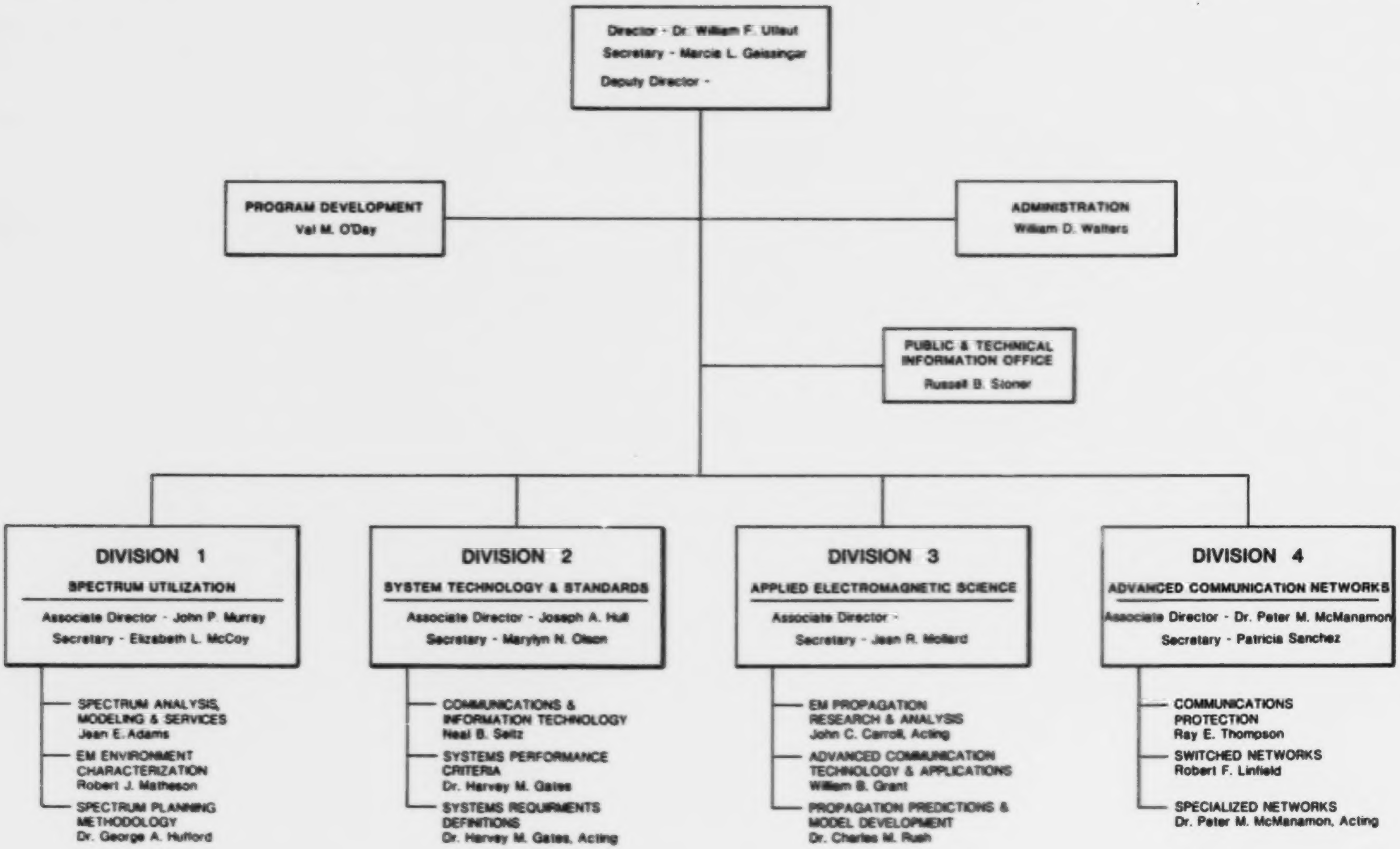
In January 1981, Dr. William F. Utlaut assumed responsibility for the direction of the Institute. A major re-evaluation of programmatic and organization structure is being carried out under his direction to re-define and aline the efforts of ITS to meet changing requirements and responsibilities.

ITS and its predecessor organizations have always played a strong role in pertinent scientific (URSI), professional (IEEE), national (IRAC), and international (CCIR) telecommunications activities. The director of CCIR from 1966 to 1974 was Jack W. Herbstreit, a former deputy director of CRPL and ITSA, and the current CCIR Director is Richard C. Kirby, formerly director of ITS. At the present time, the U.S. preparatory work for two of the eleven Study Groups of CCIR is chaired by members of ITS (U.S. Study Groups 1 and 6), and staff members of ITS participate in many of the other Study Groups. ITS actively supports the Interdepartment Radio Advisory Committee (IRAC), and the chairman of its Standards Working Group (J. A. Hull) is a member of ITS management.

The work which ITS does for other agencies in the Government derives its legal authorities from 15 U.S.C. 272(3) "Advisory Services to Government Agencies on Scientific and Technical Problems" and 15 U.S.C. 272(f) "Invention and Development of Devices to Serve Special Needs of Government." As a matter of Federal policy, NTIA does not accept work more appropriately done by other nongovernment or government organizations. It is also a matter of policy that all sponsored work reinforce NTIA's overall program and that it be clear that other agencies, industries, or universities could not serve equally well or better.

Within these policy guides, ITS aspires to being the Federal laboratory for research in telecommunications. It is clear that the Government has a responsibility to pursue long-range studies in telecommunications which are not economically profitable for industry. It is also clear that the Government must have its own, independent laboratories to assess the significance of research conducted elsewhere. Towards these ends, ITS strives to maintain a knowledgeable staff that is working on the frontiers of technology and is in touch with the telecommunications problems of the Federal Government. The Department of Defense has long been the primary source of advanced technology. At the present time, the largest part of the other agency sponsorship of ITS comes from needs of the Department of Defense. ITS maintains, however, a significant portion of its other agency work in support of civilian Federal agencies, where there is also clear need for Government expertise in high technology areas.

# INSTITUTE for TELECOMMUNICATION SCIENCES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Secretary - Marcia L. Geissinger
Deputy Director -
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ADMINISTRATION
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ADVANCED COMMUNICATION NETWORKS
Associate Director - Dr. Peter M. McManamon
Secretary - Patricia Sanchez
COMMUNICATIONS PROTECTION
Ray E. Thompson
SWITCHED NETWORKS
Robert F. Linfield
SPECIALIZED NETWORKS
Dr. Peter M. McManamon, Acting

BEST DOCUMENT AVAILABLE